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(PHASE I)

VOLUME I - SECTION 1.0 THROUGH 6.0

1 FEBRUARY 1973

Contract NAS7-200

C. J. Schroeder
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FOREWORD

This report documents the work performance by North American Rockwell Corporation through its Space Division in fulfillment of a Task Authorization entitled "Insulation Commonality Assessment," sponsored by the National Aeronautics and Space Administration's George C. Marshall Space Flight Center, Huntsville, Alabama. The work performed under Contract NAS7-200 in accordance with Task Authorization 2026-TA-48 by members of the Structural Systems, Flight Dynamics, and Manufacturing organizations of the Space Systems and Applications Division. Contributions to the efforts also were made by the Division's Safety, Quality Assurance, Reliability, and Laboratories and Test Organizations.

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CRYOGENIC STORAGE SYSTEM
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HIGH TEMPERATURE SYSTEM

ABSTRACT

THE INSULATION COMMONALITY ASSESSMENT STUDY WAS PERFORMED TO CONSOLIDATE ALL THE DATA ASSOCIATED WITH INSULATION DESIGNS. THE SCOPE OF THE STUDY WAS LIMITED TO THE DESIGNS ASSOCIATED WITH THE S-II STAGE, S-II DERIVATIVES, AND TECHNOLOGY STUDIES. DATA WERE GATHERED FOR VARIOUS INSULATION DESIGNS AND ORGANIZED INTO A DESIGN MANUAL FORMAT.

THIS REPORT CONTAINS THE RESULTS OF PHASE I OF A TWO-PHASE STUDY. PHASE II PROPOSES TO PREPARE A REPORT SYNOPSIS ON DATA EXTRACTED FROM APPROXIMATELY 30 NASA REPORTS AND REPORTS ON THE APOLLO HEAT SHIELD ABLATOR.

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1.0 INTRODUCTION

1.0 INTRODUCTION

The recent Apollo/Saturn space program gave rise to rapid technological advancements in the field of rocket propulsion, especially as related to the use of cryogenic propellants. These advances were paralleled by significant accomplishments in the design and application of cryogenic insulation materials and associated systems to support the cryogenic propulsion systems. The insulation technology has been developed through contributions of the many NASA subcontractors in support of the Apollo/Saturn program. Because different companies were involved, many different designs and different materials were used in some instances to resolve similar problems. It is the intent of this insulation commonality program to minimize redundancy in future space programs and to assure selection of an optimum design for a specific application.

Since the scope of this effort was very large, it was decided to do the program in two phases. Phase 1 would utilize only data available on insulation systems and materials generated by NR on the Apollo/Saturn programs. Phase II would utilize data supplied through studies conducted by other companies under NASA-sponsored contracts, Apollo heat shield ablator design and development reports and limited laboratory test program.

This report covers Phase I, the assembly and organization of all data on insulation system materials and designs generated under the S-II, S-II derivatives, and S-II Advanced Technology Studies. A profile of the Saturn S-II stage is shown in Figure 1.1-1. Its location relative to the Saturn V stacked configuration is shown in Figure 1.1-2. The Saturn S-II stage is the second stage of the Saturn V vehicle and is located between the S-IC and S-IVB stages. The S-IC provides thrust for the first 150 seconds of boost and the S-II takes over for the next 390 seconds of boost. The insulation systems on the S-II must, therefore, function through the total 540 seconds of boost. Areas on the S-II stage requiring insulation were the LH_2 tank (sidewall including forward and aft skirt, and forward bulkhead), feed lines, common bulkhead, interstage, LOX sump, and heat shield.

Studies, defined as S-II derivatives, were conducted to evaluate usage of the S-II stage as a booster for missions other than Apollo. These included the Space Station, Reusable Nuclear Stage, and Space Tug. Insulation designs for barriers over foam to protect insulation from the effects of large protuberance heating conditions were studied. A Saturn Intermediate-21 (INT-21) which utilized a polyimide erosion barrier design is shown in Figure 1.1-3.

S-II developed technology (S-II Advanced Technology Studies) also was directed toward evaluating insulation systems for vehicles with long-term in-orbit requirements, such as the Chemical Interorbital Shuttle (Figure 1.1-4). These studies included evaluation of usage of multilayer insulations (MLI) for boost and orbit protection of the LH_2 and LOX propellants for the orbiting vehicle. A special study under the technology program was performed to evaluate the usage of the NARSAM (a concept consisting of embossed/single-side aluminized Mylar without an intervening spacer between layers) for the CIS insulation.

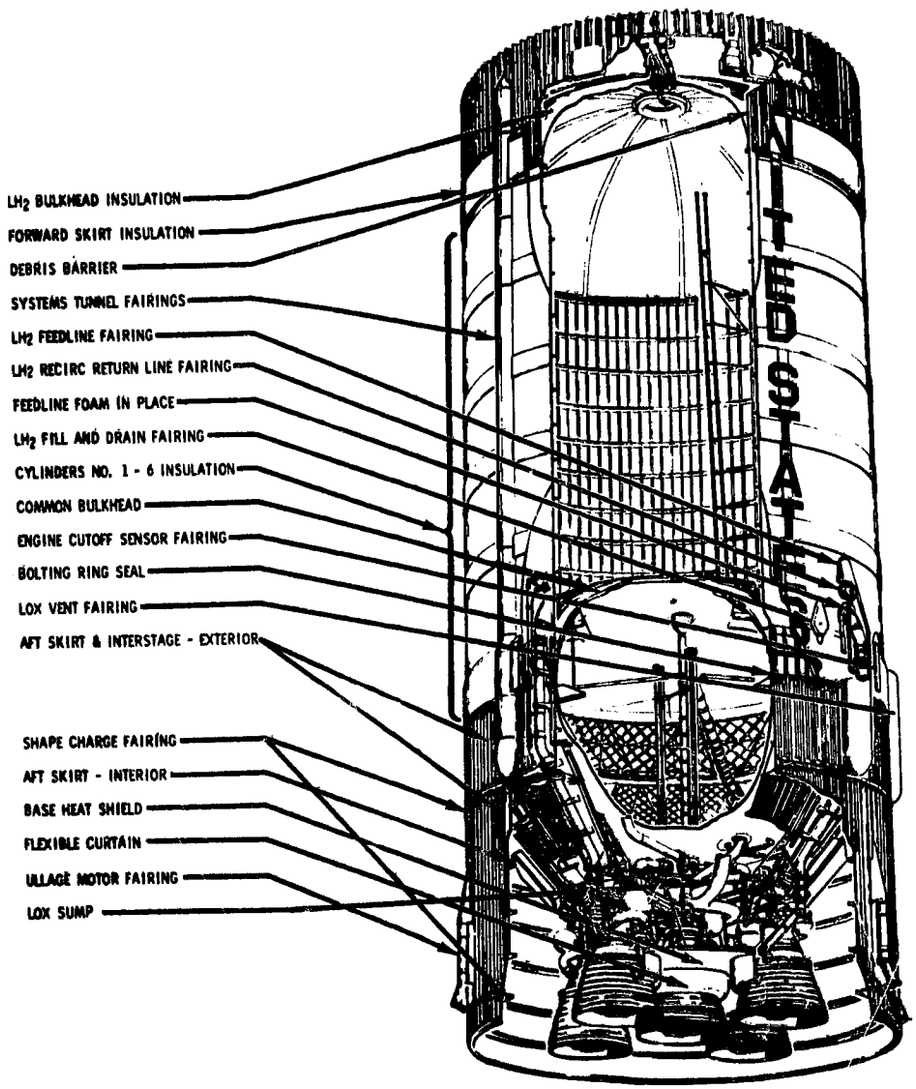

Figure 1.1-1. Saturn S-II Stage

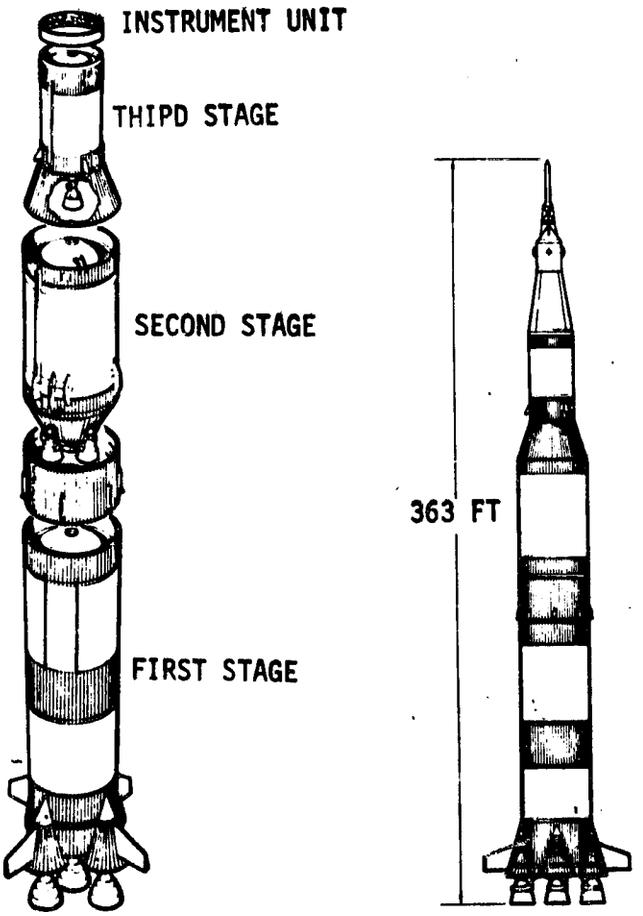

Figure 1.1-2. Saturn V

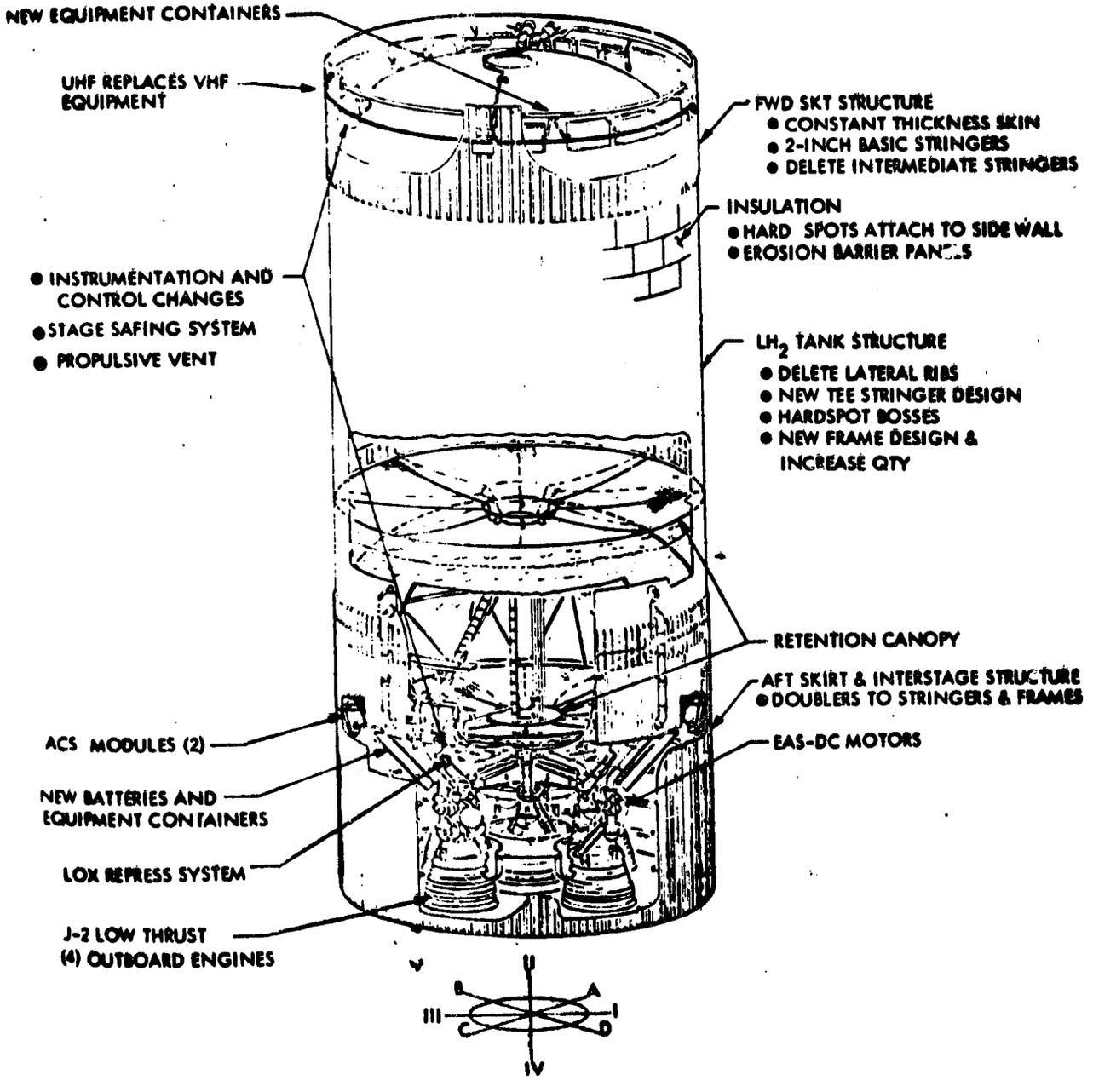

Figure 1.1-3. Modifications to S-II-15 for Total INT-21 Capability (Space Base/RNS Missions)

1-1/2 STAGE CONFIGURATION

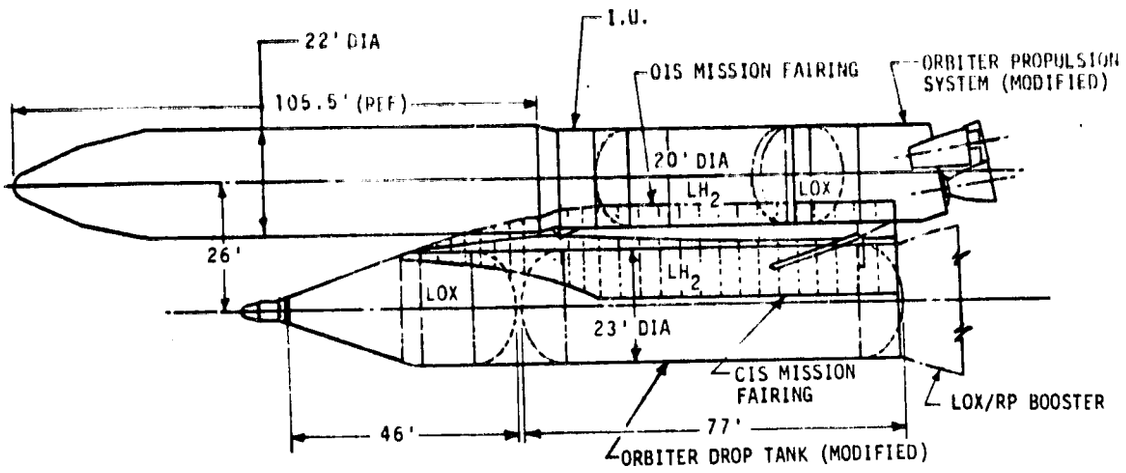

Figure 1.1-4. CIS Vehicle Concept

Phase II, which has been negotiated with the NASA contracting officer representative, will expand the effort under Phase I to include data on ablative materials studied by NR under the Apollo program and information from approximately 30 NASA reports. These new data in combination with the Phase I data will be reviewed, categorized, and compiled. Data deficiencies will be defined and tests conducted as applicable to obtain the required data.

1.1 PHASE I REPORT DESCRIPTION

This report is an accumulation of information and data gleaned from the documented reports issued on the S-II program and from inputs supplied by persons directly involved on the program. Following the summary (Section 2.0), the report is arranged in a sequence to cover the steps a designer would follow in designing a specific insulation system.

Before consideration and commencement of design, guidelines must be defined to determine how and under what conditions the design must function. The guidelines that were used on the S-II program are presented in Sections 3.0, 4.0, and 5.0 of the report. These cover the flight criteria for the various S-II and S-II derivative missions, the environmental criteria, and a definition of design requirements.

The specific insulation designs implemented on the S-II program, including specific design details, problems, solutions, reliability, and manufacturing details, are described in Section 6.0.

Sections 7.0, 8.0, and 9.0 describe the thermal, structural, and dynamic methods of analysis. The thermal section describes basic

principles of heat transfer, methods of heat transfer analysis, and some practical applications of these principles and methods in the design of insulation systems and components. The structural analysis section describes methods of predicting stress conditions in the insulation systems. The dynamics analysis as related to the S-II derivative studies is presented in the third section of the analysis group.

The remaining sections of the report - 10.0 through 18.0 - are associated with material properties and processes for insulation systems and components, reliability and safety considerations, test methods, design effectiveness, and applicable documents and references from which data in the report were obtained.

1.2 PHASE I REPORT USAGE

This report is primarily limited to information. It supplies background data on the various insulation materials and systems used on the Saturn S-II and studied for S-II derivative and related technology studies. It does provide a designer with a very comprehensive background on many insulation designs and their uses. If a designer has a particular structure on a space vehicle or booster vehicle that must be insulated he can go to the report and determine if his requirements are comparable to those given under the requirements section. He can then go to the design section and review the different designs and materials that have been used, thereby getting some insight as to their application to his particular problem. The additional sections can be utilized to assist in conducting analyses of insulation systems and to evaluate material and process characteristics. Test methods also are described which can assist a designer in determining the best technique for obtaining any desired properties data of the selected materials.

An added feature of the report is a computer program containing more than 300 reports. Cross referencing provides the ability to select a report based on a material or process specification, type of material, usage, or commercial designation. A sample of the computer program printout is presented along with a definition of how to obtain data from this program.

2.0 SUMMARY

2.0 SUMMARY

2.0 SUMMARY

This report describes the results of the Phase I portion of this study. The document is intended to assist a designer in the selection of an insulation system for a particular application. Sections 3.0, 4.0, and 5.0 of the report summarize the requirements data. Section 3.0 (Flight Criteria) gives a definition of the boost history of the Saturn V and Skylab missions and the S-II derived missions. Curves are presented which show altitude, relative velocity, dynamic pressure, thrust-to-mass ratio, all as a function of time, for a typical nominal Saturn V mission. Curves are also presented comparing dynamic pressure versus mach number and altitude versus relative velocity for the various missions.

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Section 4.0 (Environmental Criteria) describes the natural and induced environments used for design. The natural environment includes wind, wind shears and gusts, atmospheric density, pressure, temperature, solar radiation, humidity, precipitation, salt spray, sand and dust, fungus, ozone concentration, atmospheric electricity, and space. Curves and tables concerning these environmental parameters are given. Induced environments include (1) the ground environment as controlled for processing, testing, ground firing, launch pad operations, and transportation; (2) the boost environment which is associated with venting and inflow during boost, external pressure conditions (pressure distribution, aerodynamic pressure, plume impingement pressure, fluctuation pressures, base pressure), external heating (aerodynamic heating, separated flow heating, plume heating), and external shear (aerodynamic shear, plume impingement shear); and (3) the earth-orbital environment made up of the plume impingement environment, the external pressure environment, and the external heating environment. Curves giving these various environmental conditions as a function of related parameters such as time and temperature are presented.

Section 5.0 (Design Requirements) presents detailed design criteria used for basic designs on the S-II and related studies. Data are included which describe the insulation performance characteristics as related to meeting specific requirements for the propellant systems, pressurization systems, and structural systems. Data on the interaction of the insulation design and the environment, both natural and induced are presented.

Section 6.0 (Insulation Design) defines the insulation systems used on the Saturn S-II, S-II derivative, and Advanced Technology Studies. The types of insulation systems and the particular vehicle where these systems were applied are summarized in Table 2.0-1. The systems are categorized into cryogenic storage, cryogenic transfer, high-temperature protection, and other insulation systems. Data in Section 6.0 are presented for each system on the basis of:

a. Description

b. Application

c. Thermal performance

d. Structural performance

e. Materials and processes

f. Manufacturing

g. Quality assurance

h. Repair and maintenance

i. Reliability

j. Safety

k. Design effectiveness

Sketches and drawings are included which show system details and installed configurations. Curves and tables are given to show performance and functional characteristics.

Thermal, structural and dynamic methods for basic insulation performance analyses have been prepared and are presented in Sections 7.0, 8.0 and 9.0. Section 7.0 (Thermal Performance Analysis) discusses the modes of heat transfer, conduction, radiation, and convection and gives equations used to estimate the individual contributions of these modes to the overall insulation thermal performance characteristics. Data are included which give the temperatures of the insulation at various locations on the S-II stage and heat leak rates and total accumulated heat leaks to the LH_2 for the various trajectories.

Section 8.0 (Structural Performance Analysis) contains a discussion, with equations, on methods of analyzing the structural characteristics of the insulation systems. References are given for additional methods of structural analyses.

Table 2.0-1. Insulation System Description

System	Vehicle Effectivity	Area Installed
Cryogenic Storage		
Helium Purged, Foam-Filled Honeycomb Core	S-II-1 - S-II-7	LH_2 sidewall
Bonded Honeycomb, No Filler, Purged and Evacuated	S-II-1 - S-II-15	Common bulkhead
Helium-Purged, Foam-Filled, Honeycomb Mechanically Attached Over Bonded Foam Blocks	S-II-1 - S-II-7	Forward skirt
Spray-On Foam	S-II-6 - S-II-15	Forward bulkhead, cylinder No. 1 bolting ring
Spray-On Foam	S-II-8 - S-II-15	LH_2 sidewall and forward skirt
Pour Foam	S-II-1 - S-II-15	Closeouts, repairs
Pour Foam Blocks Plus Foam Blankets	S-II-1 - S-II-5	Cylinder No. 1 and bolting ring
Cork Over Foam	S-II-6 - S-II-15	S-II protuberance areas vicinity of feed lines, fill lines, recirculation lines, systems tunnel, ramps
Polyimide Erosion Barrier--Mechanically Attached	Expendable Second Stage INT-21	Bolted over foam in protuberance regions
Multi-layer Insulation Flow-Through Purge	105-in. cryogenic test tank (NASA MSFC)	Complete circumference
Multi-layer Insulation Flow-by Purge	Chemical Interorbital Shuttle	LH_2 and LOX tanks
Polyimide/Titanium Meteoroid Barrier	Chemical Interorbital Shuttle	Bolted over MLI on propellant tanks
Cryogenic Transfer		
Vacuum Jacket	S-II-1 - S-II-15	LH_2 and LOX feed lines, recirculation lines
Glass Fiber Batting--Tape Wrapped	S-II-1	LOX feed system--lines and sump
Glass Fiber Batting Encased in CRES Sheet	S-II-2 - S-II-15	LOX feed system--lines and sump
Pour Foam	S-II-1 - S-II-15	LH_2 feed lines and recirculation lines
Spray-On Foam	S-II-4 - S-II-15	LH_2 feed lines and recirculation lines

Table 2.0-1. Insulation System Description (Cont)

System	Vehicle Effectivity	Area Installed
High-Temperature Protection		
Rigid Heat Shield HRP Honeycomb	S-II-1 - S-II-15	Base area heat shield
HRP Honeycomb, Glass phenolic facing Sheet, Silica Mat Rigid Heat Shield	Orbital Injection Stage, INT-21	LM-D heat shield
HRP Honeycomb Core, Glass/Polyimide Facing Sheets	Expendable Second Stage, INT-21	Base area heat shield
Flexible Heat Shield--Glass Fabric and Batting	S-II-1 - S-II-12, S-II-14	Flexible heat shield (engine area)
Flexible Heat Shield--High Silica Fabric and Batting	S-II-13 and S-II-15	Flexible heat shield (engine area)
Cork to Metal	S-II-1 - S-II-13	Aft skirt and interstage
RTV Silicone Rubber Coating	S-II-1 - S-II-5	Interstage structural frames
Ablative Coating (Korotherm)	S-II-4 - S-II-15	Interstage structure
Other Applications		
Cork, MLI, and Fibrous Glass/Silicone Resin Binder	S-II-1 - S-II-15, INT-21	Avionic equipment
Membrane Seal	S-II-1 - S-II-15	Forward skirt forward bulkhead closeout

Section 9.0 (Dynamic Analysis) presents a discussion of the analyses conducted to determine the dynamic characteristics of protective panels bolted or bonded over the foam insulation. Results of analyses of various panel dimensions, edge conditions, and frequency modes are given.

Three sections - 10.0, 11.0, and 12.0 - present data and discussions on the thermal and structural properties of insulation materials and the methods of processing the materials. Accumulation of data, such as compressive strength, ultimate tensile strength, shear strength, modulus of elasticity, thermal expansion characteristics, and thermal conductivity for the various insulation materials, are given. Data also are presented on the erosion rates of foam insulation as determined from X-15 flight tests. Processing parameters covering the chemical compound, storage life, mixing, working life, application, and cure of the various primers, adhesives, coatings, and other insulation materials are given.

Inputs on reliability, safety, test methods, and design effectiveness are presented in Sections 13.0 through 16.0. The reliability contribution (Section 13.0) to the study included discussions on the use of failure mode effect analysis (FMEA), failure mode cause analysis (FMCA), and success logic as primary reliability analysis tools.

System Safety (Section 14.0) emphasizes such items as fabrication, ventilation, training and certification, protective clothing and equipment, housekeeping, hazards analysis, fire protection, and electrical equipment as considerations in safety analysis and prevention. A list of 44 items on a design checklist for safety evaluation is included in this section.

All test reports pertaining to the insulation designs identified in Section 6.0 were listed and retrieved. The various test methods used and data in support of Sections 10.0 and 12.0 were extracted from the lab reports. This information is accumulated in Section 15.0 (Test Methods). This also gives a sample of a computer program which allows retrieval of data from all the lab reports. Application class/chemical class, NR material specification number, commercial designation, and ASTM identification can be used as input parameters for retrieval.

Methods of evaluating various insulation designs and selecting an optimum insulation system, utilizing trade tables and appropriate trade factors, was prepared and presented in Section 16.0 (Design Effectiveness). Curves showing trade factors and value determinations are included.

3.0 FLIGHT CRITERIA

3.0 FLIGHT CRITERIA

3.0 FLIGHT CRITERIA

The flight criteria and trajectory data presented in this section are not directly applicable to insulation design but are included to show logic for developing the boost trajectory from the initial mission requirements. To determine the insulation design criteria, the trajectory data require further aerodynamic and thermal analysis. Aerodynamic studies determine dynamic loads, pressure distributions, aerodynamic heating, and temperatures (see Section 4.0). Subsequent thermal analyses determine heating rates and the heat load from the aerodynamic data.

The ability of an insulation system to protect structural elements and reduce heat leak to cryogenic propellants is directly relateable to the boost trajectory history. The boost heating will vary depending on the ascent trajectory. A shallow rate of ascent, high-velocity profile will result in higher heat inputs to a booster than a steep ascent trajectory. However, a steep ascent creates pressure and venting problems in the insulation materials and various compartments. Once the mission requirements are defined, a nominal trajectory can be generated and used to determine the mission payload capability. Design trajectories are developed using acceptable off-nominal performance of vehicle systems and atmospheric conditions. Detailed trajectory data listings are referenced and not included in this section. Instead, a design envelope is presented for use with S-II derived nominal trajectories.

3.1 MISSION DESCRIPTION

To evaluate a vehicle's performance, the mission requirements must first be defined. These requirements are defined as the orbital velocity needed at a particular altitude. With respect to payload optimization and system considerations, studies have shown that for interplanetary, lunar, and orbital flights, it is usually most efficient to park in a low-altitude orbit and, at the proper orbit location, to execute a Hohmann transfer and injection burn to the mission final velocity.

A parking-orbit altitude of about 100 nautical miles has been found to be optimum for most vehicle-mission combinations. Parking at lower altitudes may provide greater payload capability, but heating, orbit lifetime, and tracking become problems. For missions requiring orbit rendezvous, a parking altitude between 200 and 300 nautical miles is usually found to be the optimum. However, even for this mission, it is beneficial with some configurations to park initially in a 100-nautical-mile orbit and then transfer to the rendezvous orbit altitude.

For the lunar mission the S-II reaches propellant depletion before the 90-nautical-mile parking orbit is achieved. The S-II stage will also be used as the second stage, which is the terminal stage, for the Skylab I mission. In this case, the S-II engines will be shut down when the 235-nautical-mile rendezvous orbital requirements are met. Because of these greatly different mission requirements, the atmospheric boost, altitude, and velocity profiles represent the extremes for all S-II missions studies to date.

3.1.1 Saturn V and Skylab I Missions

The Saturn V lunar orbit rendezvous operational mission consists of the following flight phases:

a. Launch and boost to 90-nautical-mile earth parking orbit. This phase consists of complete burns of the S-IC and S-II stages and a partial burn of the S-IVB stage.

b. Coast in a circular parking orbit for up to three revolutions while subsystem checkout is performed. First opportunity for injection occurs during the second revolution.

c. S-IVB stage reignition and boost to translunar injection during one of two injection opportunities from parking orbit.

d. Command-service module separation, transposition, and docking with the lunar module/S-IVB, and CSM/LM ejection from the S-IVB/instrument unit.

e. S-IVB auxiliary propulsion system evasive maneuver to reduce the probability of recontact with the CSM/LM.

f. S-IVB LOX dump, propulsive H_2 vent, and post-LOX-dump auxiliary propulsion system burn after the evasive burn to cause the expended S-IVB/IU to impact the moon within a designated target area.

The Skylab I mission consists of the following flight phases:

a. Launch and boost to 235-nautical-mile earth orbit insertion, inclined 50 degrees. This phase consists of a complete burn of the S-IC stage and a partial burn of the S-II stage.

b. Orbital coast with separation of the S-II stage and the payload in orbit, a retrograde maneuver, a payload shroud jettison, Apollo telescope mount deployment, acquisition of solar inertial attitude, deployment of ATM and workshop solar arrays, control moment gyro spinup, and activation of the ATM pointing control system.

Mission profiles for these boost configurations are shown in Figures 3.1.1-1 and 3.1.1-2.

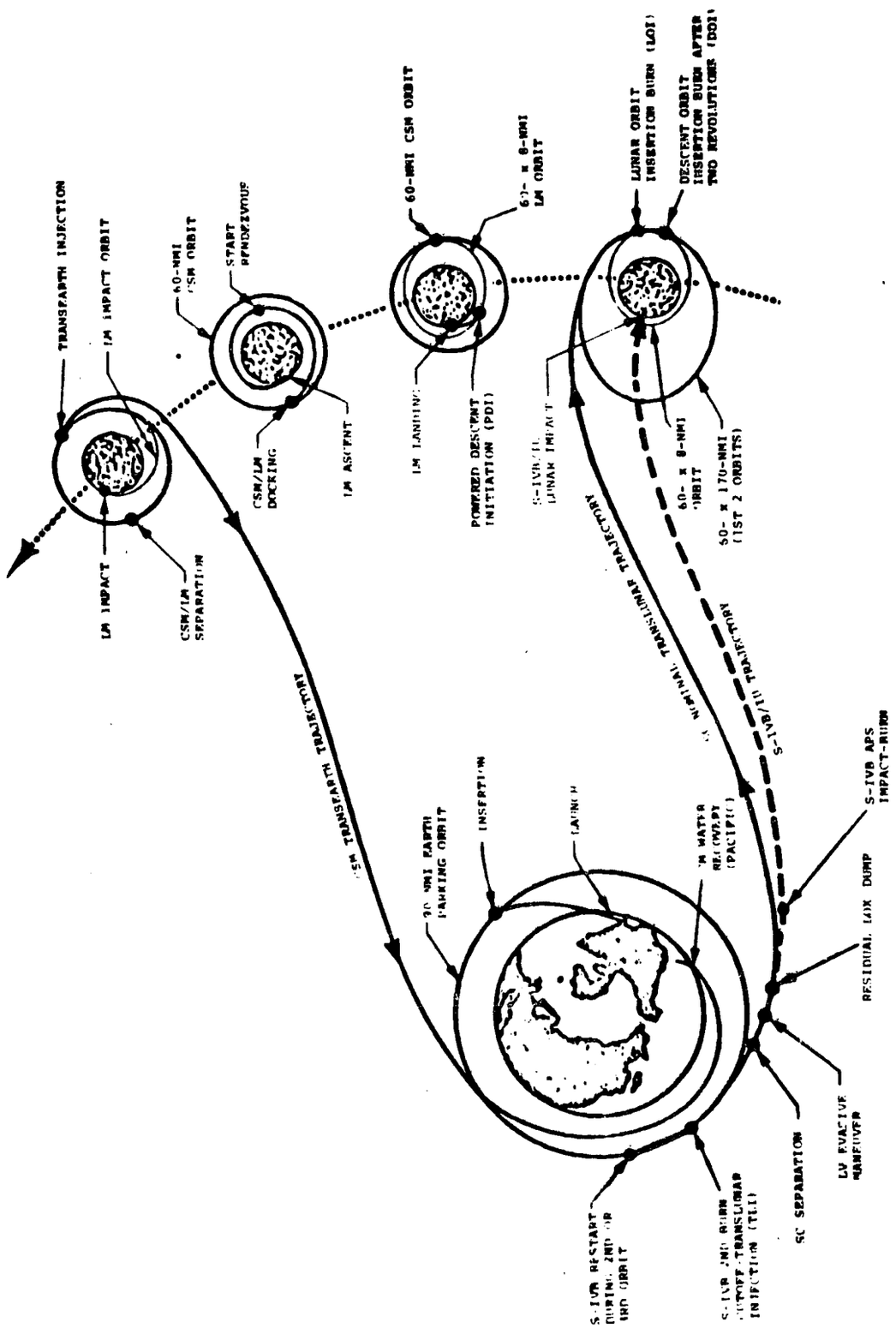


Figure 3.1.1-1. AS-511 Apollo 16 Mission Profile

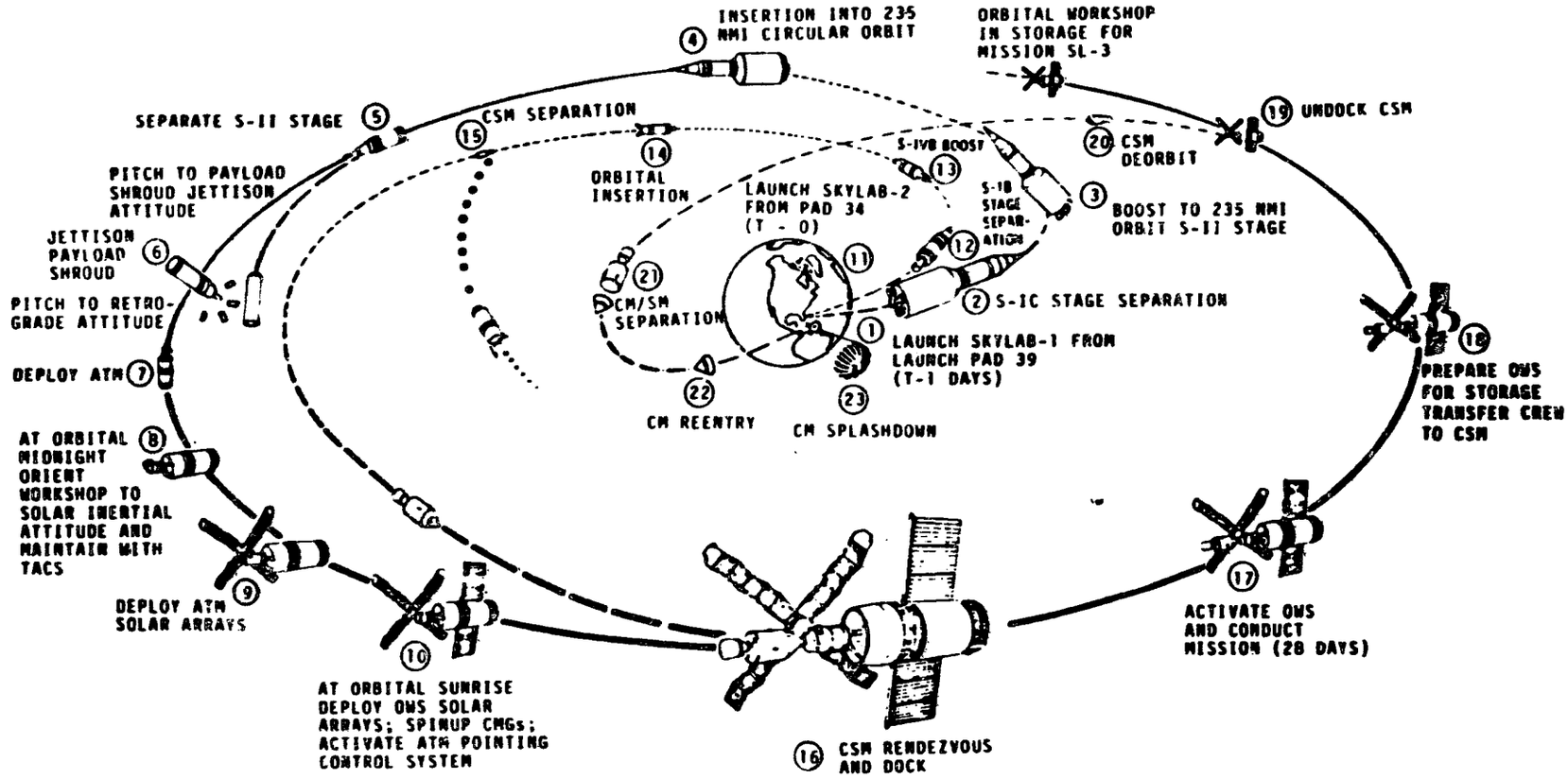


Figure 3.1.1-2. Skylab I Mission Flight Profile

Space Division
North American Rockwell

3.1.2 S-II Derivative Missions

For most S-II derivative missions, emphasis was placed on payload capability with a bare minimum insulation analyses. However, for the Saturn Intermediate - 21 (INT-21) vehicles the insulation analysis was more complete. Two different missions were studied for the INT-21 booster. In both cases the booster consisted of an S-IC first stage and an S-II final stage.

The INT-21 Space Station mission consists of the following flight phases:

a. Launch and boost to a 246-nautical-mile circular earth orbit, inclined 55 degrees to the equator.

b. Orbital coast with separation of the S-II stage and payload in orbit.

The INT-21 Space Base mission consists of the following flight phases:

a. Launch and boost to a 100 by 262-nautical-mile elliptical orbit, inclined 30 degrees.

b. Orbital coast followed by a circularization burn to place the payload in a 262-nautical mile orbit.

3.2 NOMINAL BOOST TRAJECTORIES

The mission payload capability of boost vehicles is determined by means of nominal boost trajectories. These trajectories are computed using nominal or expected input values of booster system performance and flight environment for the primary launch date mission. Backup trajectories are computed (also with nominal values) to cover the launch window and possible launch date changes. Nominal boost profile data are used for the dynamic flutter analysis of the externally mounted insulation material.

The analysis for performance evaluation involves two sets of parameters: vehicle design and trajectory. The vehicle design parameters describe the physical characteristics of the vehicle such as weight, thrust, specific impulse and drag variation. The trajectory parameters are divided into two classes: one defines the mission requirements and the other defines the required payload and on-orbit velocity requirements. Thus, the problem of determining nominal vehicle performance involves manipulating a set of input data defining the vehicle into a set of trajectory data which can accomplish the mission.

During the first-stage portion of flight, a gravity turn or "zero angle of attack" trajectory is used to reduce the aerodynamic forces acting on the vehicle. Preliminary simulations of gravity-turn trajectories are launched vertically and programmed for zero pitch for a short period. This vertical rise period depends on the initial thrust-to-weight ratio. After the vertical rise, an artificial "kick-angle" (instantaneous rotation of the vehicle centerline and velocity vector), is given to initiate the gravity turn. The kick angle is used in trajectory calculations to represent the pitchover period during actual flight before the gravity turn. The burnout flight path angle and staging weight of the first stage are dependent on the magnitude of the kick angle.

Following first stage burnout and a short staging coast period, the S-II engines are started. The iterative guidance mode (IGM) is initiated 20 to 30 seconds later (when the atmospheric effects can be neglected), and provides steering commands for the remainder of booster flight. For most S-II applications, the center J-2 engine is shut down at 140 to 300 seconds after the start command. Two-position S-II stage engine mixture ratio valves on each engine are used to minimize residual propellant. These valves are, upon command from the Instrument Unit computer, used to change the LOX/LH_2 flowrate mixture ratios from 5.4 to 4.7. For Saturn V missions, nominal engine cutoff for end-boost is initiated by depletion sensors located in the LOX tank. For Skylab I and other S-II terminal stage applications, engine cutoff is commanded by the guidance system when desired orbital conditions are reached.

3.2.1 Nominal Boost Simulation

Nominal boost trajectories to determine booster system performance are usually computed using a three-degree-of-freedom (3-D) computer program. The 3-D trajectory uses the mass of the booster concentrated at a single point, as it applies the thrust to translate the mass through a three-dimensional space reference over a rotating, oblate earth with atmospheric effects. The amount of input data required are minimized by the 3-D method. For example, the point-mass concept eliminates the need for center of gravity and moment of inertia histories and also detailed aerodynamic characteristics. The performance capability of a booster system can be assessed quickly using the expected (nominal) vehicle characteristics. Typical variation of some key trajectory parameters with time are shown in Figures 3.2.1-1 through 3.2.1-4. The profiles shown are for a Saturn V nominal boost trajectory, and may not be representative of any other boost vehicle. More detailed trajectory analysis can be made using a six-degree-of-freedom (6-D) program. For this type, the vehicle's finite length mass is used and the booster rotational history in addition to translation is computed. The 6-D program requires a vast amount of detailed input data. Although the 3-D program does not produce greatly detailed trajectory information, the payload and boost profiles closely match the values obtained using a 6-D program. As a result, the 6-D trajectory program is usually used only for final configuration analysis and off-nominal performances.

3.2.2 Data for Flutter Analysis

The primary trajectory parameters used for the insulation flutter analysis are Mach number and dynamic pressure, Figure 3.2.2-1 displays the variation of these parameters for the Saturn V/Apollo, Skylab I, and INT-21 missions (References 1, 2, and 3).

3.2.3 Orbital and Post-Orbital Data

The insulation requirements in orbital and escape flight are determined using a thermal analysis solar heating program (see Section 7.0). This program determines the sun angle with respect to the spacecraft and time in the earth's shadow. Orbital insertion data from the trajectory analysis are used as input.

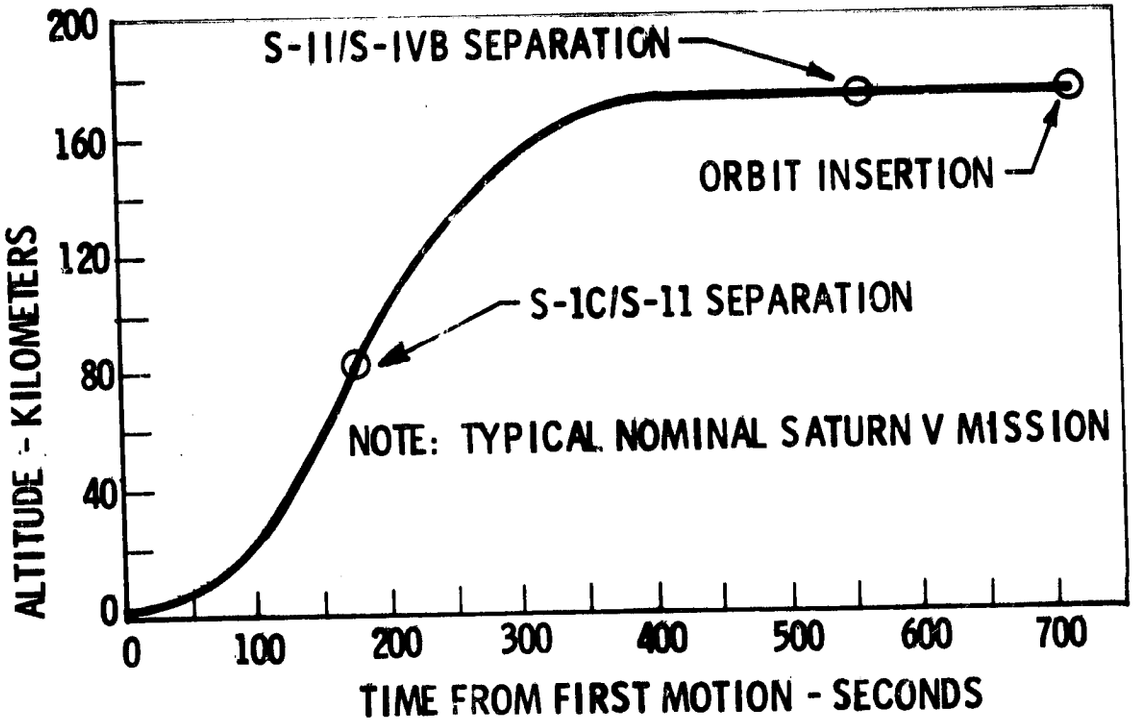


Figure 3.2.1-1. Altitude Versus Time During Boost to Parking Orbit

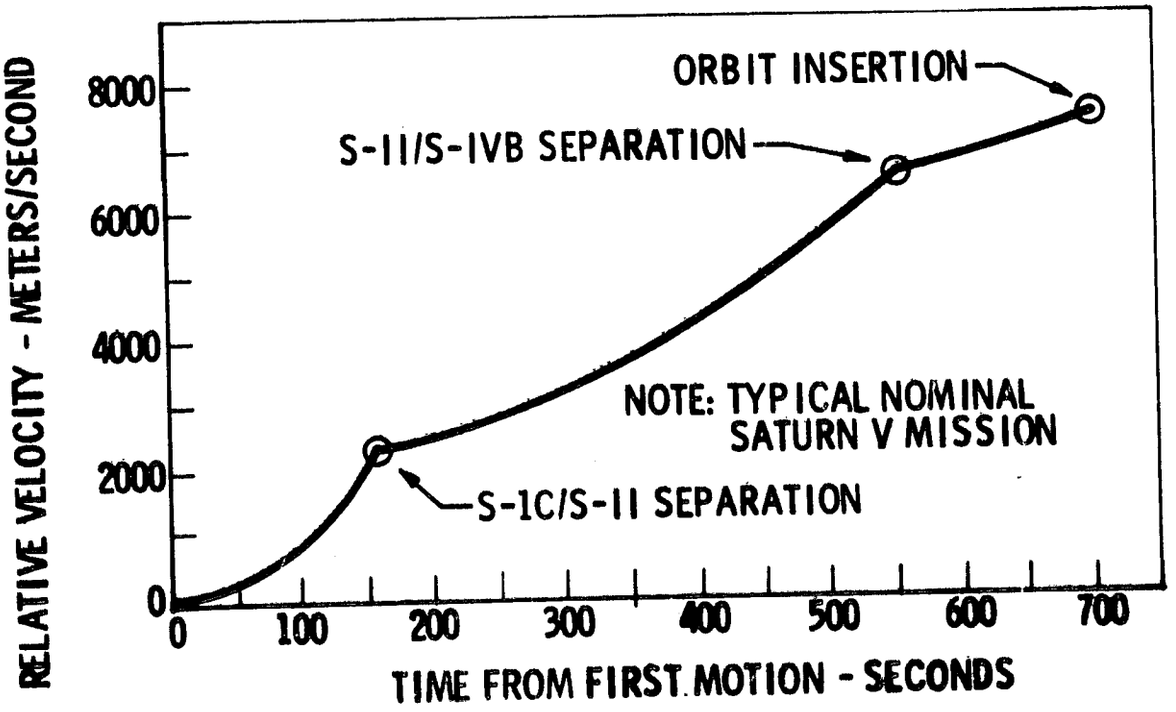


Figure 3.2.1-2. Relative Velocity Versus Time During Boost to Parking Orbit

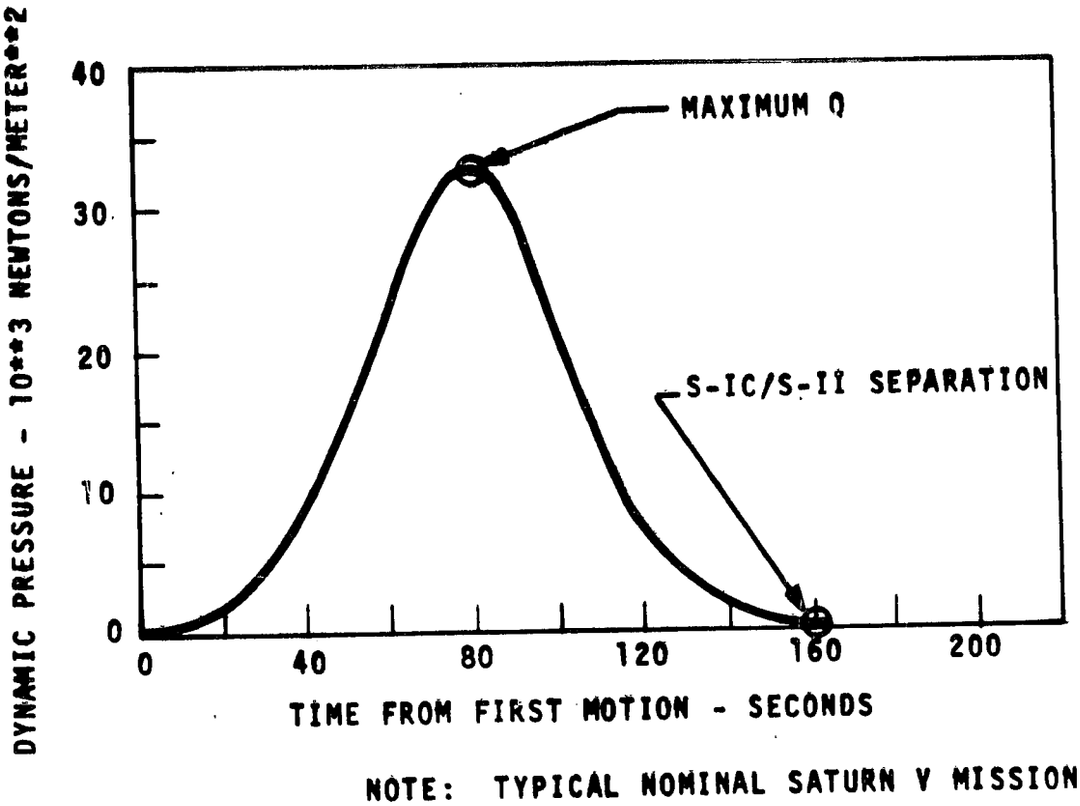


Figure 3.2.1-3. Dynamic Pressure Versus Time During Boost

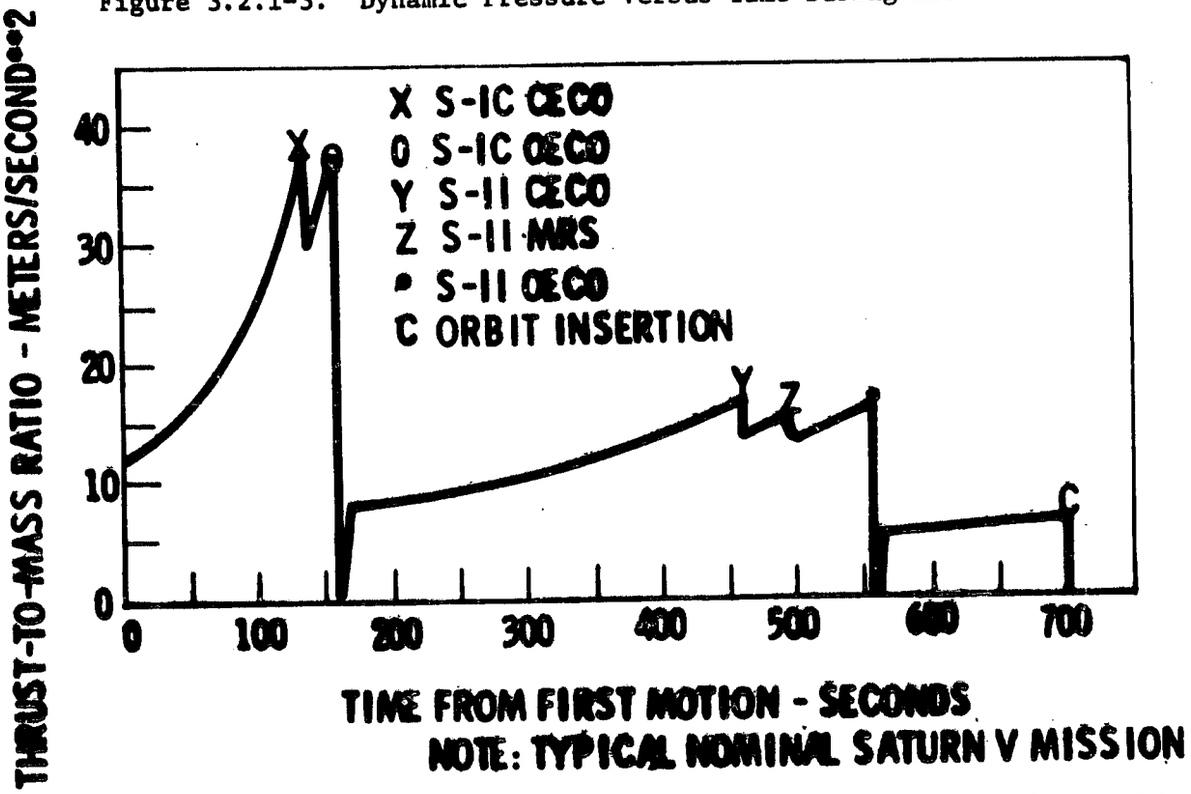


Figure 3.2.1-4. Thrust-to-Mass Ratio Versus Time During Boost to Parking Orbit

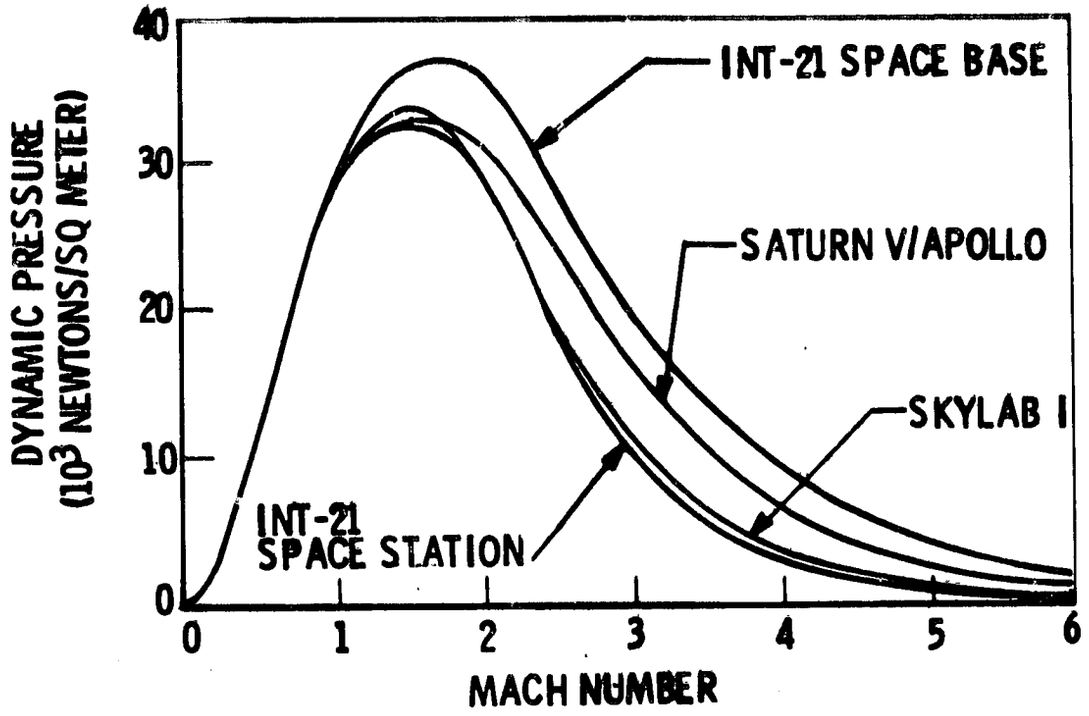


Figure 3.2.2-1. Comparison of Mach Number and Dynamic Pressure for Various Missions

3.2.4 Mission Timelines

Following the boost phase, mission timelines are important from the standpoint of plume impingement of auxiliary propulsion and reaction control systems. The duration and time between firings of these systems is determined in the guidance and control analysis. The effect of hot gas impingement on the insulation material must be considered.

3.3 DESIGN BOOST TRAJECTORIES

To be considered early in any preliminary design are the maximum anticipated loads and heating parameters. Up to this point, only the nominal or expected boost trajectories have been discussed. However, in a complex booster, each system and subsystem has an acceptable operating band about its expected nominal performance. It is these dispersions which are used to determine the aeroheating and loads design trajectories. Before the design trajectories can be computed, however, many trajectories must be calculated to determine the deviations caused by each separate dispersion. Composite design trajectories are then developed with the objective of maintaining specified parameters at, or near, the three-sigma upper value.

3.3.1 Method

A dispersion source is defined as a variation from the expected (nominal) value of a vehicle system characteristic, guidance characteristic, or the flight environment. The occurrence of a dispersion source, or group of dispersion sources, during flight causes the vehicle trajectory to deviate from the nominally defined conditions. The dispersion sources specifically defined for the Saturn V vehicle are assumed to be independent and to include the effects of all independent perturbating characteristics. Therefore, these sources are assumed to provide total envelopes for trajectory parameters.

Separate 6-D trajectories are generated for each sense, plus and minus, of each individual dispersion source. These trajectories are compared to the nominal trajectory and deviations established for selected variables at significant trajectory events or times. At these significant points (e.g., maximum dynamic pressure, S-IC outboard engine cutoff) individual deviations of most trajectory parameters are accumulated by the root-sum-square (RSS) method to yield statistical envelopes. These calculated three-sigma limits exist only at the selected significant trajectory points. Consequently, composite trajectories are now developed to provide a continuous time history for the parameter of interest at the plus three-sigma upper value.

Composite trajectories for design purposes are generated by simultaneously introducing several perturbations into the boost simulation. Selection of these perturbations is limited to the major contributors to the three-sigma envelope at the significant control point. For example, the aerodynamic heating indicator (AHI) control point is usually taken at first stage end boost, and the dispersions of crosswind, atmospheric density, and first stage weight (or c.g. displacement) are used. The resulting trajectory is adjusted, if necessary, until it closely matches the upper three-sigma boundary. This technique is used to develop design trajectories for aerodynamic heating, dynamic pressure, and maximum acceleration.

3.3.2 Design Envelope for S-II Applications

From the brief methodology described, it can be seen that development of design trajectories requires a considerable amount of manhours and computer support time. Because of this cost, detailed off-nominal trajectories have not been computed for S-II missions, other than the Saturn/Apollo and Skylab I missions. However, because of the greatly different missions (90-nautical-mile versus 235-nautical-mile orbit) for these scheduled vehicles, a design envelope can be developed to provide a quick check for other missions.

Figure 3.3.2-1 shows nominal boost velocity/altitude comparisons for the Skylab I and Saturn V vehicles. Also shown on this plot are the design trajectory traces for both vehicles (References 4 and 5). From the standpoint of aeroheating, the Saturn V design heating trajectory is the most critical for insulation design because of the high velocity at low altitude. The Skylab I design loads trajectory is critical from the insulation venting

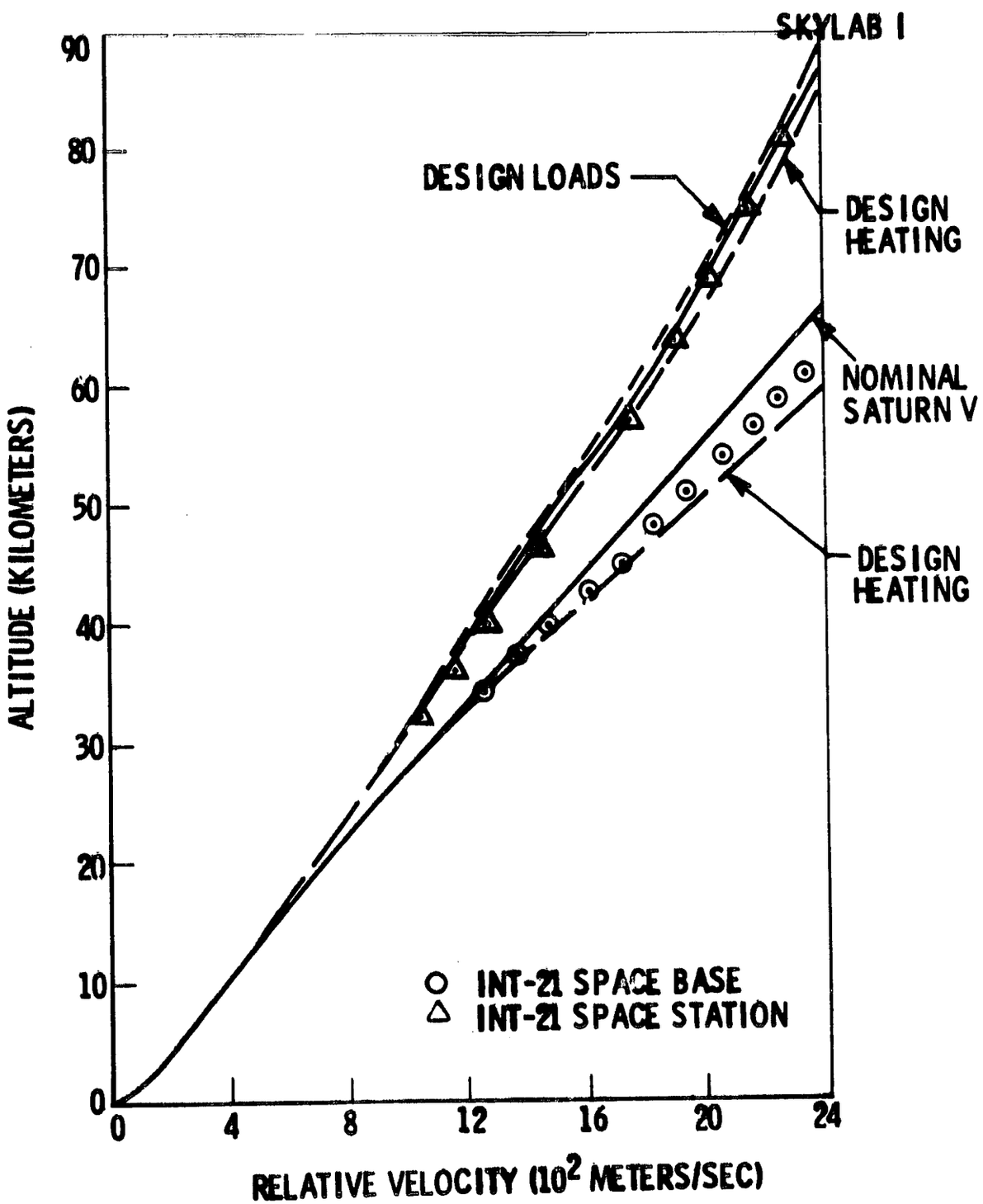


Figure 3.3.2-1. Boost Profiles

standpoint because of the steep ascent profile. These two extremes form a design envelope within which all S-II stage missions studied to date lie. For example, the relative position of the nominal boost profiles for two missions for the INT-21 are shown. This curve can be used as a quick check by aerodynamics engineers to determine heating criticality for other vehicle nominal missions. This is especially important since nominal trajectory data are usually the only boost data calculated for preliminary studies. More detailed discussions of use of Figure 3.3.2-1 is contained in Section 4.0.

4.0 ENVIRONMENTAL CRITERIA

4.0 ENVIRONMENTAL CRITERIA

The environment of an object consists of all the conditions affecting the integrity and function of the object. In the case of thermal insulation, the environment consists of all the conditions affecting the physical integrity and thermal (and structural) performance of the insulation.

This section defines the sources of information on the environment in which the insulation must survive and function. An introduction is given to the methodology used in determining the environment, with the aid of the information sources. Using the insights of this section the designer becomes aware of the wide range of parameters he must consider in the design of the insulation system, in addition to its function as insulation.

The environment can be described as "natural" (climatic), that is, existing independently of the existence of the object, or as "induced", dependent on the presence of the object. In general, the "induced" environment is dependent on the interaction of the object with the natural environment. The "natural" environment will be discussed first.

4.1 NATURAL ENVIRONMENT

The natural environment includes winds, wind shears and gusts, atmospheric density, pressure and temperature, solar radiation, humidity, precipitation, salt spray, sand and dust, fungus, ozone concentration, atmospheric electricity and the space environment.

The rate of change of the "environment" and duration of the environment and the combinations thereof are particularly important and should be examined.

The design natural environment for a vehicle should be defined in the contractual document specifying the vehicle. The insulation design should be reviewed to determine compliance with each pertinent requirement in the vehicle specification. If the "design" natural environment is not defined in detail in the vehicle specification, great care must be given to select limits of the natural environment corresponding to the "probability of occurrence" utilized for design of other vehicle components. However, the impact of insulation failure on vehicle safety, crew safety and mission success must also be considered.

4.1.1 Ground Environment

The basic guidelines for the natural ground environment for space vehicles are presented in Reference 6. This reference contains design guideline values for the following environmental parameters: thermal (temperature and solar radiation), humidity, precipitation, winds, pressure, density, electricity (atmospheric), sand and dust, fungi and bacteria, atmospheric oxidants, and atmospheric composition. In most cases extreme values, as well as most probable values, are given. Since Reference 6 was developed for use in design of NASA space vehicles, emphasis is given to those areas where NASA space vehicles are produced, tested, transported, and launched.

It should be anticipated that Reference 6 will be updated and expanded with more coverage on the Western Test Range and Shuttle landing sites. The latest revisions of these documents must be consulted prior to design.

For other aerospace vehicle insulation applications (e.g., Air Force), there are similar guidelines or contractually specified documents which must be consulted. Earlier versions of Reference 6 were utilized in defining the environment for the S-II stage (NR Specification CP621M0014A). Except where noted, the natural environment for the S-II stage is the same whether the stage is used for Lunar Orbital Rendezvous (LOR) or Skylab missions.

Certain climatic extremes for S-II stage design for the LOR mission are presented (NR Specification CP621M0014A) in Table 4.1.1-1. For the Skylab mission, the flight altitude increases to about 1,200,000 feet. Information on the natural environment for the S-II stage was also provided in NR Reports SID61-473-1 and SID63-498.

The use of these sources, especially the latest revisions of Reference 6, and equivalent documents, should provide the necessary definition of the ground environment except for areas greatly different from the geographic areas included in these documents. In the latter case, analogous material must be developed using available sources of information, such as local weather bureau or military base records.

4.1.1.1 Transportation Environment

The natural transportation environment for insulation consists of the natural environment (Reference 6) through which the thermally-insulated object passes, together with the environment through which insulation components pass prior to final application. Examples would be (1) unpressurized cargo compartments of aircraft, where rate of change of pressure would be important, and (2) shipping through the Panama Canal.

The natural transportation environment for the S-II stage is specified (NR Specification CP621M0014A). The same criteria would apply for any aerospace vehicle insulation, with the requirement for determination of environment for passage through any greatly different environment. To clarify the latter point, the use of insulation at a sea level equatorial launch site could require consideration of more severe environmental design parameters than presented in Reference 6.

4.1.1.2 Pad Environment

The pad environment consists of the natural environment at the specific locations where the space vehicle is checked out, tested or launched. Isolated spots have been used as launch sites, typically in desert regions or near sea transportation. Significant pad locations for the S-II stage included the Eastern Test Range, the Mississippi Test Facility, the White Sands Missile Range (New Mexico), the Rocketdyne Field Laboratory in Santa Susana (California), and NASA/MSFC (Alabama). The Western Test Range (California) is planned for use for polar orbit launches.

Table 4.1.1-1. Climatic Extremes (NR Spec. CP621M0014A)

Environment	Extreme
Temperature (non-operating, storage and land or sea transportation; operating, static firing and launch)	9 F minimum to 107 F maximum, with 24-hour temperature change cycles as follows: A rise of 50 F in a 5-hour period; 4 hours of constant temperature; a decrease of 50 F in a 5-hour period; 10 hours of constant temperature. Compartment temperature factor as defined in paragraph 2.7 of NASA TMX-53023.
Air Transportation (components)	-85 F to +125 F for 8 hours
Flight	-85 F minimum ambient
Altitude (nonoperating) Storage Land and sea transportation Air transportation (components) Air pressure range	 0 to 2000 feet 0 to 6000 feet 0 to 35,000 feet 1041 mb to 255 mb
Altitude (operating) Static firing and launch Flight (equipment operating) Flight (engines operating)	 0 to 2000 feet up to 700,000 feet 175,000 to 700,000 feet
Humidity	0 to 100 percent with condensation
Rain and freezing rain	up to 4 inches per hour for one hour
Snow load	up to 2 lb/ft^2 in a 24 hour period
Salt spray	As to be encountered at KSC
Sand and dust	As to be encountered in Operations
Fungus	As in tropical regions
Ozone	Three year exposure to 3.0 ppm concentration with a maximum of 6.0 ppm for 12-hour periods

The natural environment to be used for these locations is presented in Reference 6, NR Specification CP621M0014A, and NR Report SID61-473-1. For clarity it is important that a specific environment be utilized.

4.1.2 Earth Atmosphere

The atmosphere of the earth can be defined by its pressure, density, temperature and composition. Most of the other properties, such as speed of sound, viscosity, and conductivity, can be obtained from a knowledge of the first-named parameters. The properties of the atmosphere vary over the surface of the earth, vary with time of day, and with time of year and, in the upper atmosphere, with sunspot activity. In addition, the properties vary from the mean values presented in most atmospheric tables. Current models of the earth's atmosphere are presented in References 7 and 8. Specific atmospheres over certain earth locations have also been developed. S-II stage (NR Specification CP621M0014A) has specified use of Reference 9 for the S-II stage launched from KSC (Florida). Atmospheric information is also presented in NR Report SID63-498. Information from these sources is used in determining the induced environment for insulation.

The steady wind direction, wind speed, and gusts are also considered as part of the atmospheric environment of the earth. The flight winds to be used for the S-II stage are specified (NR Specification CP621M0014A, NR Reports SID61-473-1 and SID63-498). An extract of this information is presented in Table 4.1.2-1. Reference 6 contains guidelines on winds for future generations of space vehicles. Winds vary significantly in direction and velocity profile during the year. As a result, preflight predictions involving wind will vary with launch date. However, the winds listed in the quoted references are used for design purposes. Again, for launch and landing sites at other locations, "winds" data must be developed from historical records for the locality.

4.1.2.1 Nominal Atmospheric Conditions

The bulk of the atmospheric data presented in References 7, 8 and 9 refers to the nominal atmospheric conditions. These conditions are usually consistent with an atmospheric temperature lapse rate for altitude bands of the atmosphere. However, it is likely that any measurement of an atmospheric parameter will deviate from the nominal (model) value. For this reason, design values for atmospheric parameters must allow for variations from nominal values. (Special care should be exercised to make certain that the appropriate values are used for structural design, nominal max design, payload level or insulation design conditions.)

4.1.2.2 Off-Nominal Atmospheric Conditions

Information for off-nominal conditions for the atmosphere is presented in NR Specification CP621M0014A, NR Report SID63-498, and References 6, 7 and 8. Consideration has been given to these off-nominal conditions when designing vehicles or components. An example of the density extremes possible at one location is shown in Figure 4.1.2.2-1. Again historical records for a specific site should be consulted to determine local atmospheric extremes.

Table 4.1.2-1 Cape Kennedy Area Flight Wind, 95 Percentile
(MIL Spec CP621M0014A)

ALTITUDE		WIND SPEED	
KILOMETERS	FEET	METERS PER SECOND	KNOTS
1	3,280	21	40.8
10	32,800	75	145.8
14	45,900	75	145.8
20	65,600	25	48.6
23	75,490	25	48.6
50	164,000	102	198.3
80	242,400	102	198.3

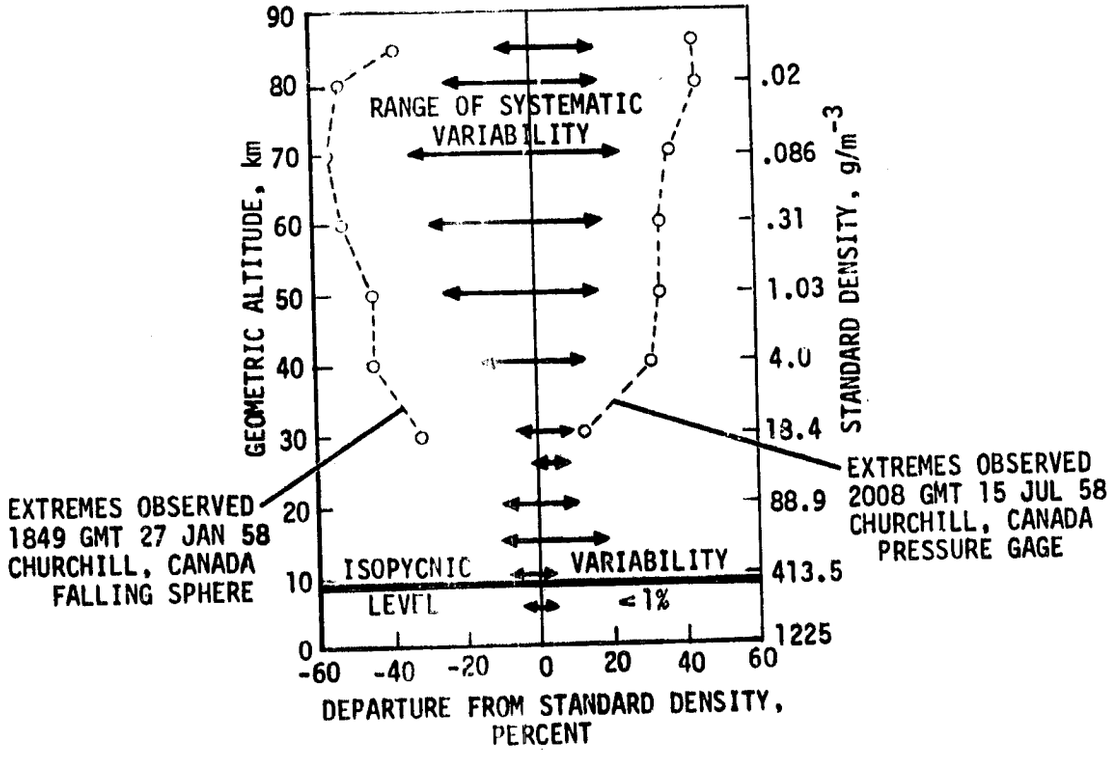


Figure 4.1.2.2-1 Range of Systematic Variability of Density About U.S. Standard Atmosphere, 1962

In certain cases, an off-nominal atmosphere is specified for use as part of a criterion.

4.1.3 Earth Orbital Environment

Below 90 km, the information on natural environment in Reference 6 is to be used for NASA space vehicle design guidelines. For terrestrial space, Reference 10 is to be used. Information is presented in Reference 10 on neutral gas properties, the ionosphere, the radiation environment, the meteoroid environment, the geomagnetic environment, and winds. These references have been updated as a result of space activities. It is expected that future space flights will result in additional updating of these references. Thus, care must be exercised to use the latest version of the document.

The document also includes guidelines for cislunar space, interplanetary space, and lunar and planetary environments.

4.2 INDUCED ENVIRONMENT

The induced environment consists of the environment resulting from the interaction of an object with the natural environment, of the interaction of one subsystem of the object on another subsystem, and of the interaction of the object with the natural environment perturbed by another portion of the same object, or by another agency. Examples of each of these types of interaction will be mentioned in the subsequent paragraphs.

4.2.1 Ground Environment

The induced ground environment can be considered as starting with the selection and initial processing of the raw materials for the insulation, continuing through all the manufacturing and assembly processing and storage operations, final application to the object being given the thermal protection, and the controlled atmosphere prior to and during flight (e.g., nitrogen or helium purging). This environment is covered in the manufacturing and quality control portions of the study.

Damage due to inadvertent contact with tools and vehicles must be considered. The induced ground environment should also include those tests to which an insulated object is subjected. For instance, a vibration test of an insulated tank could impose strains on the insulation, though generation of those strains may not be a test objective. Ground firing and launch pad environments will be considered separately in Paragraph 4.2.1.2.

4.2.1.1 Transportation Environment

The induced transportation environment is concerned with the impact of the movement of the insulation components or insulated object from place of manufacture to assembly to test to vehicle stack assembly to launch pad. Some of the main imposed loads are the "handling" loads, characterized by accelerations (bumps). These accelerations can be experienced in hoisting operation, in transfers from hoist to transportation device (truck), during

motion of truck on road surfaces, during braking and acceleration, during transfer to aircraft or barges, during aircraft acceleration, in response of aircraft to wind shear during flight, in response to wave motion, during barge docking, and during aircraft landings and takeoffs.

The design values of ground handling, transportation and erection loads for the S-II stage were specified (Reference 6) as 2g in all directions. The S-II stage land transportation speed was limited to 5 mph to keep loads within limits.

4.2.1.2 Pad Environment

The pad environment herein is considered as the environment on static firing test stand as well as on the launch pad. The pad environment includes the environment while the stage is inert, while loaded with propellants, and while the engines are firing. The intermediate states and associated states are also part of the pad environment. The intermediate states include fueling and defueling, the associated states include purging and venting operations. The pad environment also may include tool damage and spills of hypergolic propellants.

a. Purge and venting on pad: In order to prevent freezing of atmospheric moisture and air components on cryogenic propellant tank surfaces or on adjacent insulation, both compartments and insulation may be purged while on the pad or test stand prior to, during, and after propellant loading. The flow rates through the insulation must be checked to insure that damage would not result through a "rippling" type of load (for Multi-Layer Insulation, for example). The differential pressure across the insulation must also be limited to prevent structural damage to the insulation facing sheets, or to MLI. (This differential pressure was a problem with the helium-purged, foam-filled honeycomb insulation on the S-II stage.)

b. Fluctuating Pressures: Steady winds flowing past a launch vehicle, orbiter, or the various launch towers or test stands, can react with the object to result in a turbulent wake. This turbulent wake flowing over an object causes the surface to experience a fluctuating pressure environment. Thus, the S-II stage surface was subject to a fluctuating pressure field due both to its own interaction with the wind, and to the fluctuating pressure wake from the towers. Surface insulation, and insulation relatively open to the atmosphere, must endure this fluctuating pressure environment. These fluctuating pressures, as well as wind gusts, can cause differential pressures across insulation facing sheets or intermediate insulation layers, which pressures must be considered in design. Scale models of tower and vehicle are tested on a rotatable pad in a wind tunnel to help evaluate fluctuating pressure loads, and determine frequencies. An example of the results of such a test on a Titan model with umbilical tower is reproduced here as Figure 4.2.1.2-1 (Reference 28). This figure should not be used, nor should any illustration in Section 4.0, without determining the specific conditions for which it was valid, or determining whether it has been superseded.

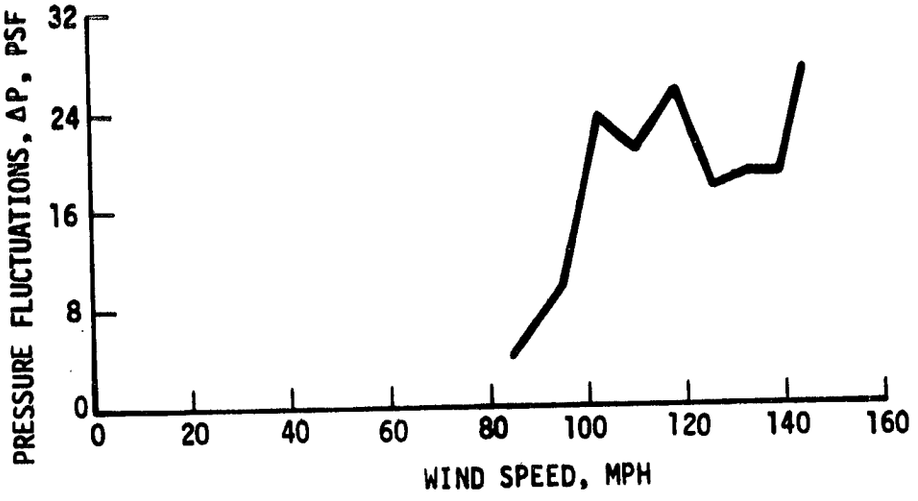


Figure 4.2.1.2-1 Pressure Fluctuation Test Data on Titan Model and Umbilical Tower

c. Fluctuating Pressures (Rocket Engine Noise): The operation of rocket engines within the atmosphere results in noise due to the shear between the exhaust gas and the atmosphere, and due to the operation of pumps at high speeds. The mechanical noise of pumps is transmitted through the launch vehicle structure to the insulation. The sound (fluctuating pressure) from the rocket exhaust is transmitted through the atmosphere to the sides of the launch vehicle. Some of the sound is reflected from the sides of the test stand or launch towers; another apparent sound source is at the flame bucket.

NASA has prepared a monograph (Reference 11), on the acoustic loads generated by the propulsion system. This should be used for design loads for new insulation applications. The external and internal acoustic environment used for the S-II stage is presented in NR Specification CP621M0014A and in NR Report SID61-473-1, as is the structural vibration for various regions of the S-II stage. An example of the external acoustic environment generated by the S-IC engines firing on the pad is presented in Figure 4.2.1.2-2, reproduced from NR Specification CP621M0014A. Where insulation consists of panels supported at discrete location, significant strains could be transmitted from the basic structure to the insulation.

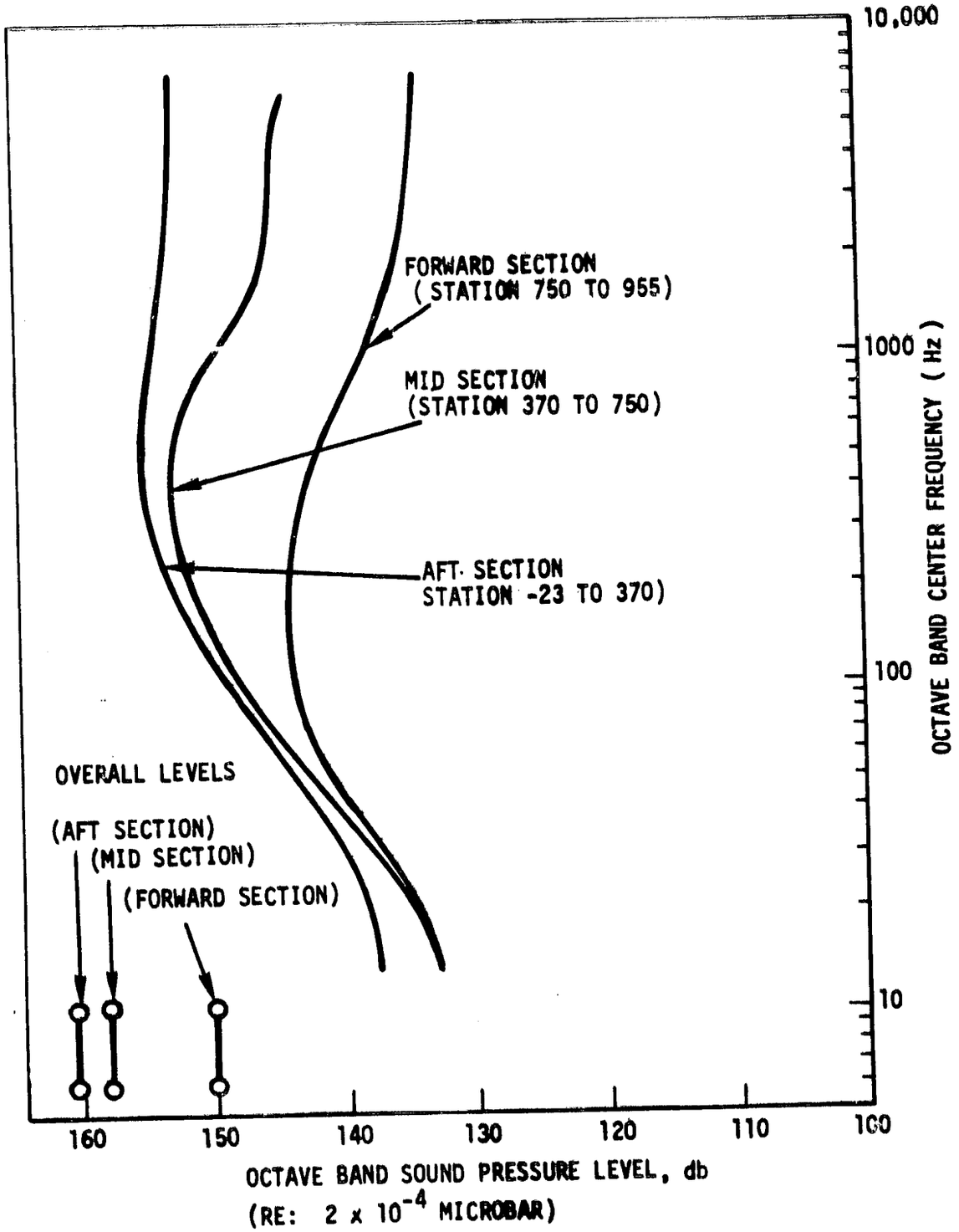


Figure 4.2.1.2-2 External Acoustic Environment for S-II Stage, Restrained Firing Condition

d. Thermal Environment: Where cracks or other paths exist through the insulation to a cryogenic propellant tank, cryopumping can result from the liquefaction and freezing of air components at the tank wall, resulting in maintenance of a pressure differential along the crack. Rapid warmup of the tank wall as a result of detanking and tank purging can result in the rapid warming of the liquified and frozen air components and conversion to gas, with resultant high pressure within any gap adjacent to the wall. This process resulted in formation of debonded plugs (divots) of spray foam on the LH_2 tank wall of the S-II stage for several vehicles.

4.2.2 Flight Environment

The flight environment commences at lift-off and, for this study, terminates when the vehicle reaches orbital altitude. For this study, the flight environment will not include entry into planetary atmospheres.

4.2.2.1 Compartment Venting and Inflow

The unpressurized compartments (and insulation cavities) at lift-off will contain a purge gas at a pressure somewhat above atmospheric. The temperature of the gas will vary throughout the various compartment and insulation areas depending on the purge gas flow pattern and temperature of the structure bounding the flow paths. Just prior to lift-off, the piping connecting the purge gas supply and exhaust is disconnected and the compartment can vent to the atmosphere. The pressure-time history in these compartments is a function of the initial gas pressure, temperature and composition, the flow paths and the restrictions in the paths for the gas to flow to the atmosphere, and the external pressure-time history at the controlled vent and at the leakage locations. The external pressure-time history is a function of the vehicle configuration and trajectory. In general, during boost the pressure within the compartment or insulation will be higher than the ambient pressure at the altitude being transited. The external local pressure at the vent or leakage location at any moment can be either less than or greater than the pressure just inside the vent or leakage area. Thus, at any instant the flow may be outward or inward. Of course, during boost to orbit, the general trend is for outward flow of the purge gas to the atmosphere.

As a result of the differences between internal pressure (assumed constant within a compartment at any instant) and the external pressure (varying with position on the vehicle around the compartment perimeter and along the compartment length), there is a compressive or a burst differential pressure load on the compartment walls. There are also compartment bulkhead loads, due to the difference in pressures in adjacent compartments, and insulation differential pressure loads, due to the difference in pressure from within the insulation to the compartment resulting from pressure lags during venting of the insulation. NASA has published a guideline document (Reference 12) on compartment venting for space vehicle design.

The design values of maximum differential (burst) pressure on the S-II forward skirt and aft intertank, resulting from venting lag and vehicle attitude and configuration, are presented in NR Specification CP621M0014A and NR Report SID63-498. An example of the internal and differential (burst) pressure time histories in the S-II stage forward skirt is presented in Figure 4.2.2.1-1 reproduced from NR Specification CP621M0014A.

NR Report SID63-498 also contains a discussion of the methodology used in determination of the internal and external pressure environments. NR Specification CP621M0014A contains the design trajectory used in the venting calculation.

NR has developed a multiple compartment venting digital computation program, which was used for predicting pressure-time history in both compartments and in helium-purged insulation. Comparison of the predicted pressure-time history and the measured pressure-time history for an instrument in the helium purged insulation is presented in Figure 4.2.2.1-2. A prediction of the longitudinal differential pressure across the sidewall insulation for the S-II-6 insulation configuration and design trajectory is presented in Figure 4.2.2.1-3.

4.2.2.2 External Pressure Distribution

The external pressure distribution environment on a vehicle during transit through an atmosphere may consist of an aerodynamic pressure environment, a plume impingement pressure environment, a fluctuating pressure environment, and/or a base pressure environment. These environments will be discussed separately in the following paragraphs of this report.

a. Aerodynamic Pressure: The external aerodynamic pressure distribution on a vehicle is a function of the vehicle configuration, atmosphere (including winds), and trajectory (including vehicle attitude). There are many methods of analysis available for determining the aerodynamic pressure, the best being reliance on wind tunnel tests on a model of the vehicle, with proper evaluation of difference between model test and full scale vehicle conditions (e.g., Reynolds number, roughness, etc.).

   The external pressure distribution on a vehicle with external insulation is thus the external pressure distribution on the insulation. The pressure distribution on, or in the vicinity of protuberances, differs from the clean body pressure distribution. Also, when determining the pressure distribution for the full-scale vehicle from wind tunnel tests of scaled models, the relative spacing of instrumentation and discontinuities in shape must be considered.

   The Saturn V LOR mission configuration is shown in NR Specification CP621M0014A, with protuberances presented in Interface Control Document (ICD) 65ICD9000. The Skylab configuration has been published (Reference 13) and its protuberances presented in ICD 651CD9001. The aerodynamic pressure distribution on the basic Saturn V configuration and on protuberances is presented in NR Report SID63-498. An example of the longitudinal distribution of surface pressure coefficient is presented in Figure 4.2.2.2-1, reproduced from NR Report SID63-498.

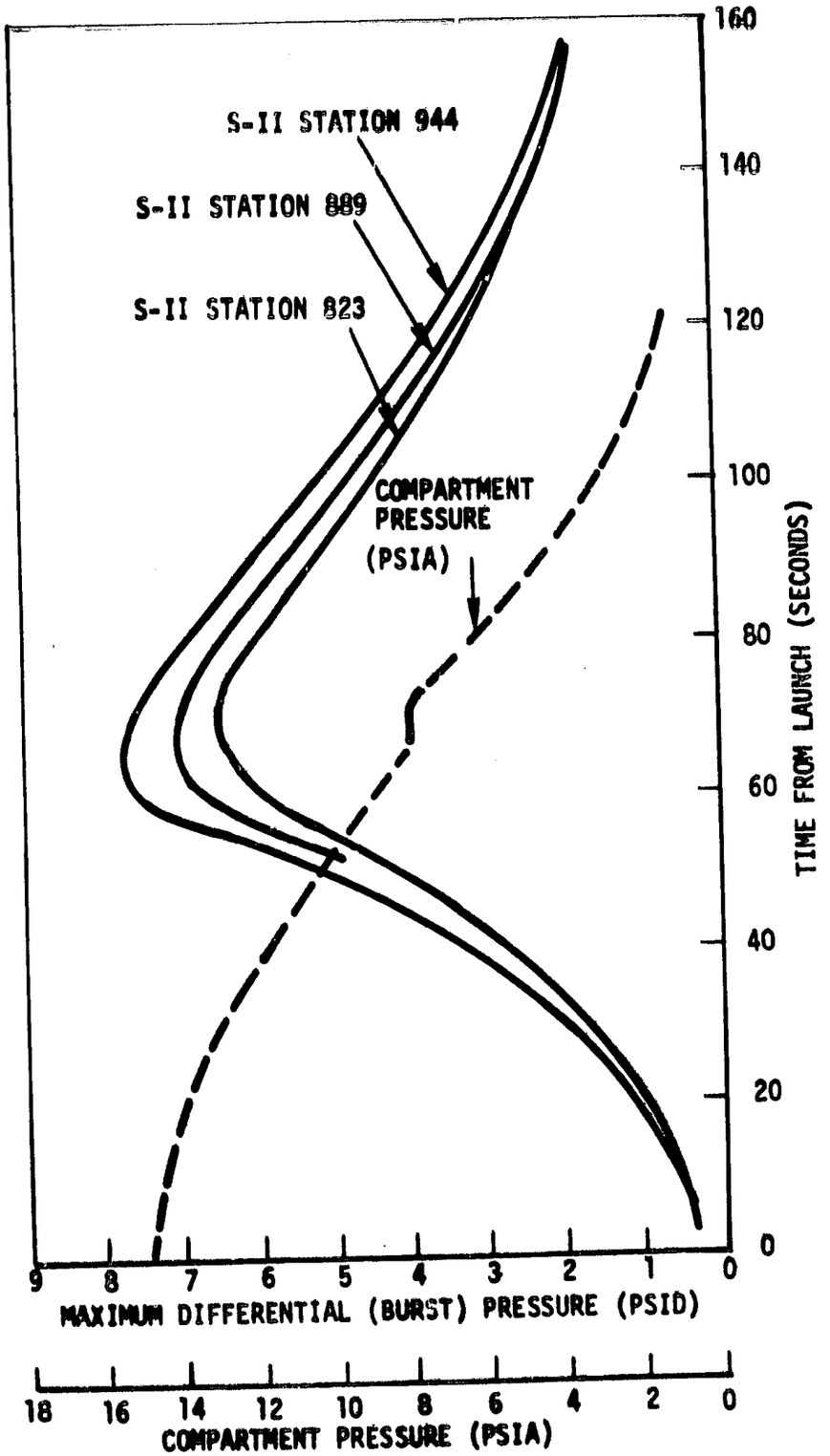


Figure 4.2.2.1-1 Maximum Differential (Burst) and Compartment Pressure for S-II Stage Forward Skirt

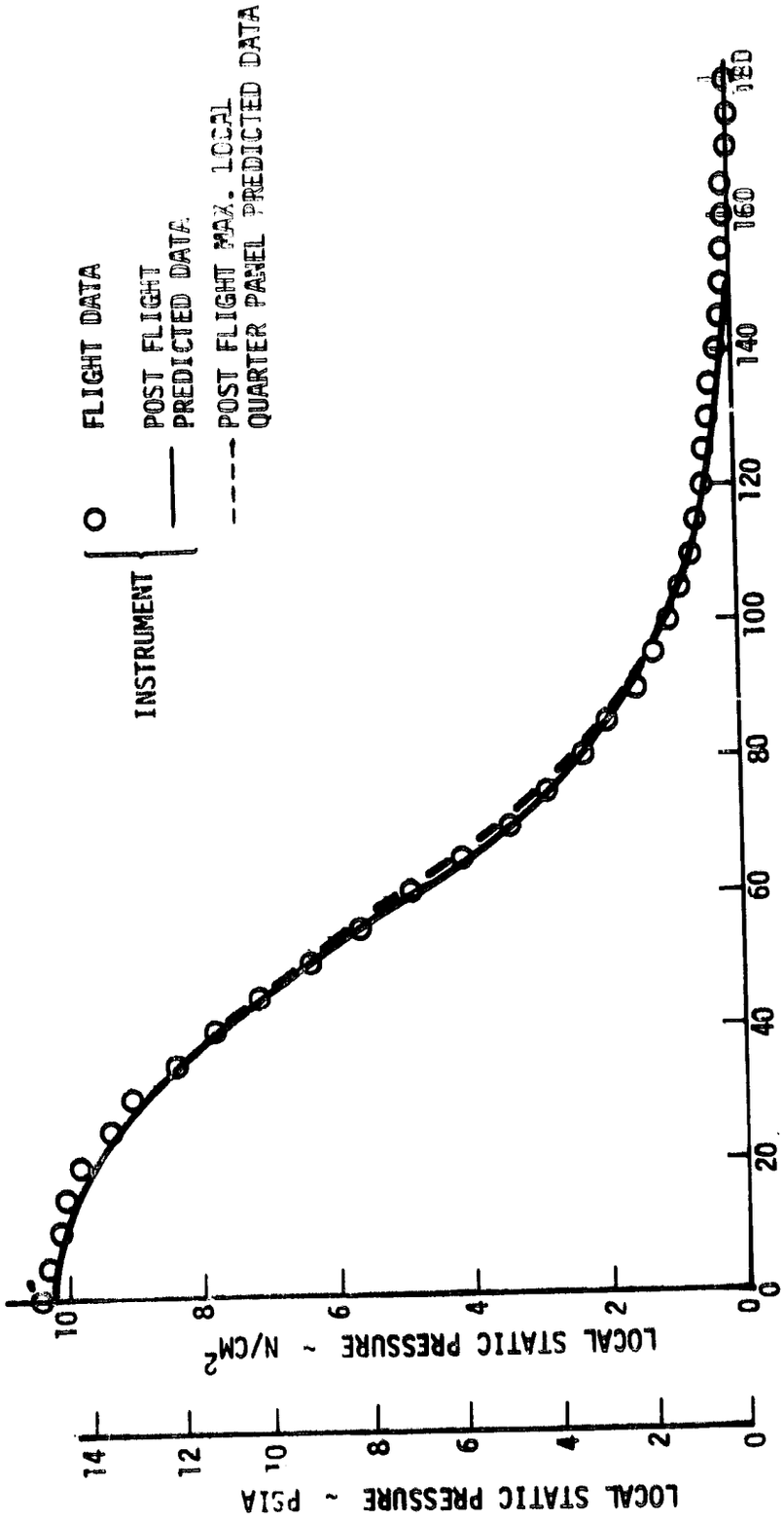


Figure 4.2.2.1-2. LH_2 Sidewall Insulation Internal Static Pressure

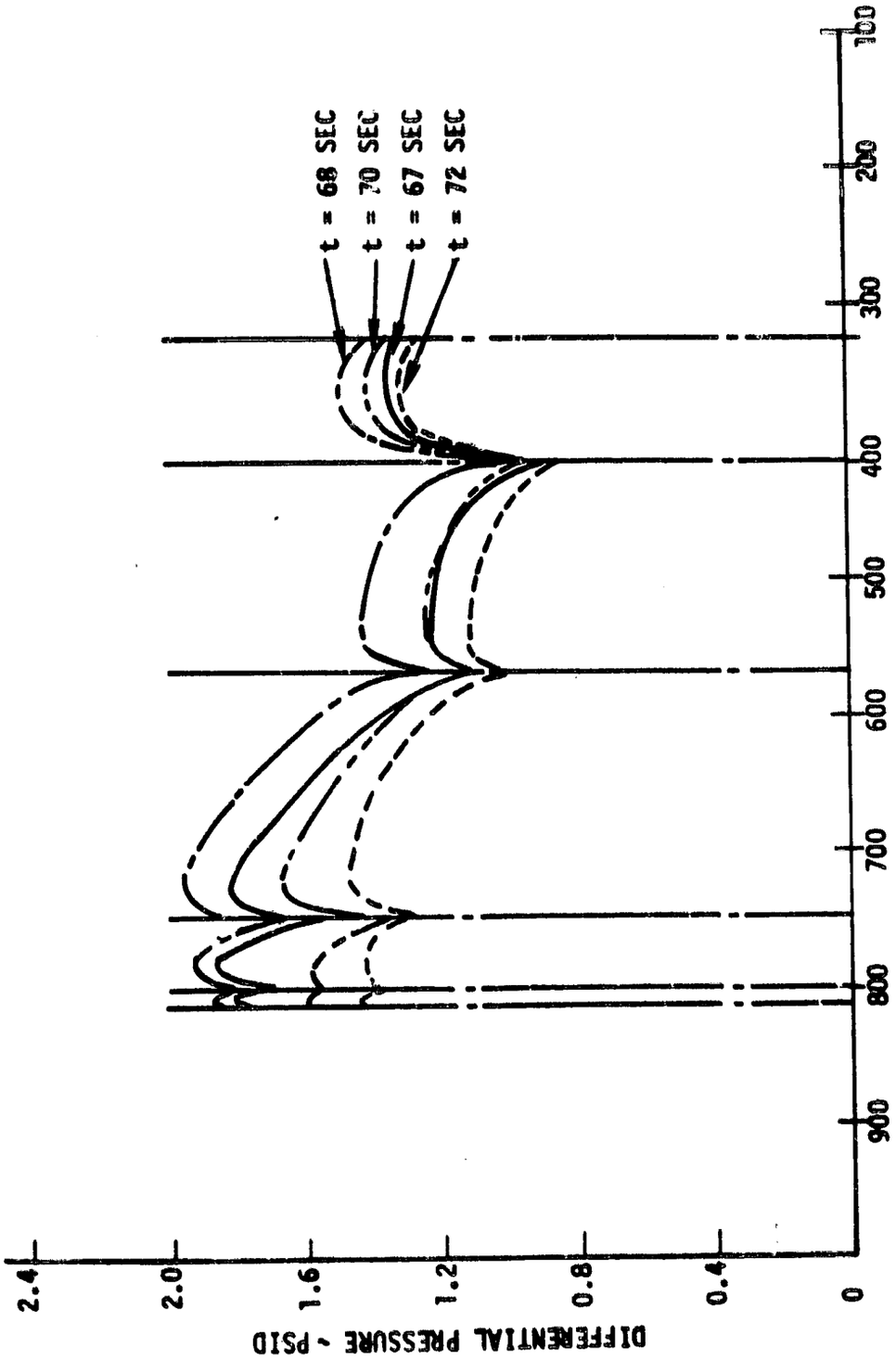


Figure 4.2.2.1-3. Pressure Profile Versus X_B Stations Based on AS-506 Design Trajectory

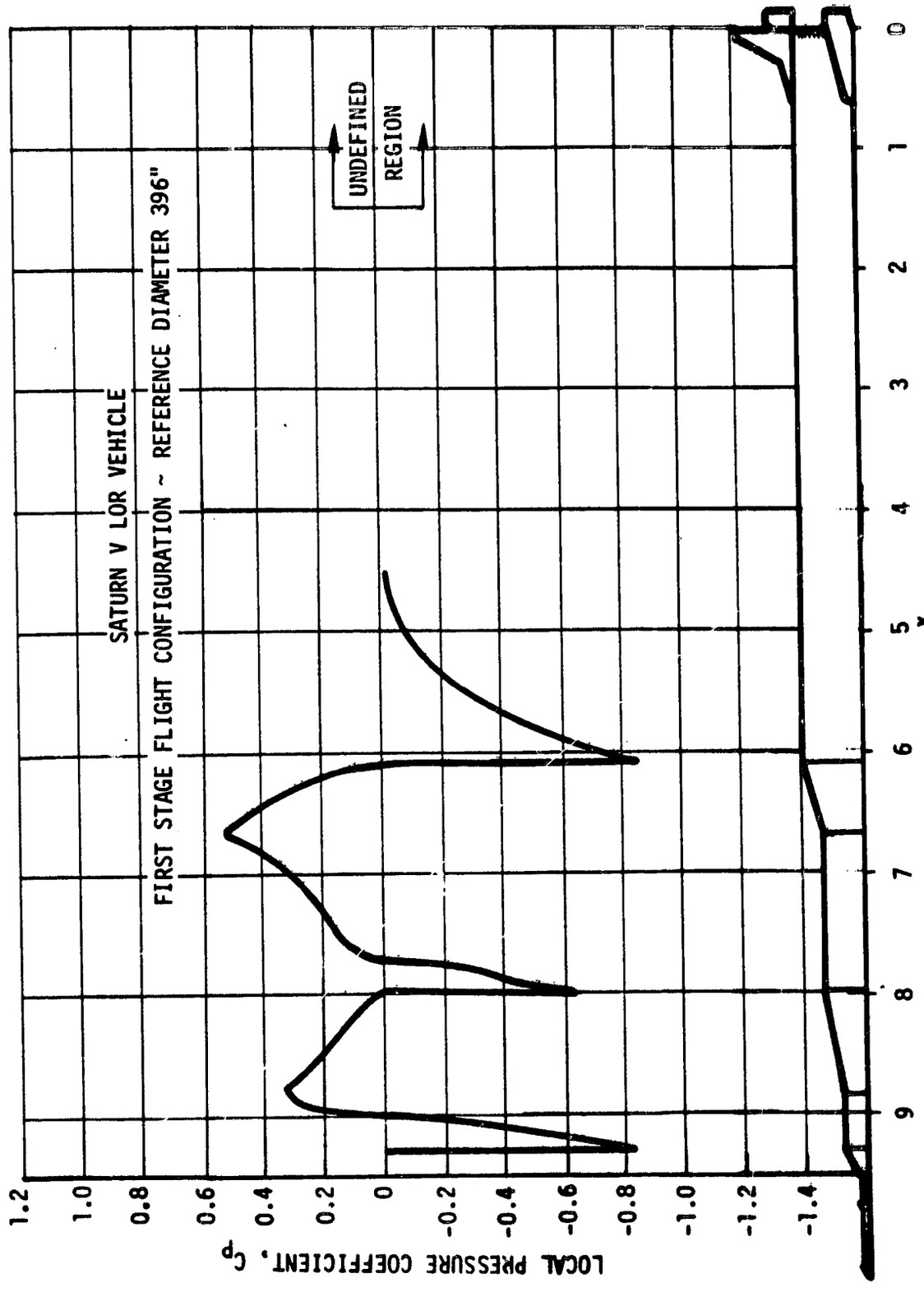


Figure 4.2.2.2-1. Distribution of Local Pressure (Coefficient at $\alpha = 0$; $M = 1.00$

b. Plume Impingement Pressure: Launch vehicles often contain retrorockets, ullage rockets, attitude control jets, and similar devices producing exhaust gas plumes which interact with the external atmosphere and produce pressure disturbances on adjacent surfaces. The duration of firing of these jets may be short, but the resulting forces may produce effects other than expected, in attitude control or in drag, for example. In addition, the pressure gradient produced along a surface may be of opposite direction to that normally anticipated, thus leading to flow of hot plume gases into regions where such flow is undesirable (into MLI or Reusable External Insulation, for example). Analysis of these interacting flow fields, i.e., of the plume with the external flow, is quite complex and should be verified by test.

c. Fluctuating Pressures: Fluctuating pressures on the exterior of launch vehicles are due to aerodynamic causes and to rocket exhaust noise. Fluctuating pressures due to the latter cause are usually greatest at lift-off, have been discussed in Paragraph 4.2.1.2c, and will not be discussed further. Fluctuating pressures from aerodynamic causes exist due to turbulence in the boundary layer, to shock oscillation, and to separation and reattachment of flow. The maximum external acoustic environment for the S-II stage during boost, reproduced from NR Specification CP621M0014A, is presented as Figure 4.2.2.2-2. Much work has been done in experimental measurement of pressure fluctuations and to making time/space correlations of the measurements for use in predicting structural panel response. One reference cited (Reference 14) contains information on fluctuating pressures. It was also stated therein that design criteria monographs would be issued on vibration, acoustics, and flutter.

d. Base Pressure: As a launch vehicle ascends through the atmosphere, the ambient atmospheric pressure decreases while the pressure within the engine nozzle just upstream of the exit plane remains essentially constant. As a result, the engine plumes expand laterally until they impinge on each other. Due to this mutual impingement, there develops a pressure level which lower energy flow, e.g., in the nozzle boundary layer, is unable to penetrate. This lower energy flow then reverses and flows back to the base heat shield, then laterally out between the base heat shield and the engine nozzles. The pressures exerted on the base region, due to this reversed exhaust gas flow, were considered as part of the base heat shield design, flexible curtain design, and also in the net forces on the launch vehicle. The pressures in the S-II stage base region are presented in NR Report SID61-473-1.

The base pressure is dependent on the base region nozzle location, spacing, distance from nozzle exit plane to heat shield, and gimbal patterns, and thus will differ from vehicle to vehicle. It also will vary with engine mixture ratio, center engine cutoff (CECO) mixture ratio and chamber pressure. At present, theoretical methods cannot predict the base region flow within acceptable limits for design purposes. Thus, for vehicles other than the S-II stage, the base pressure must be determined from model test data.

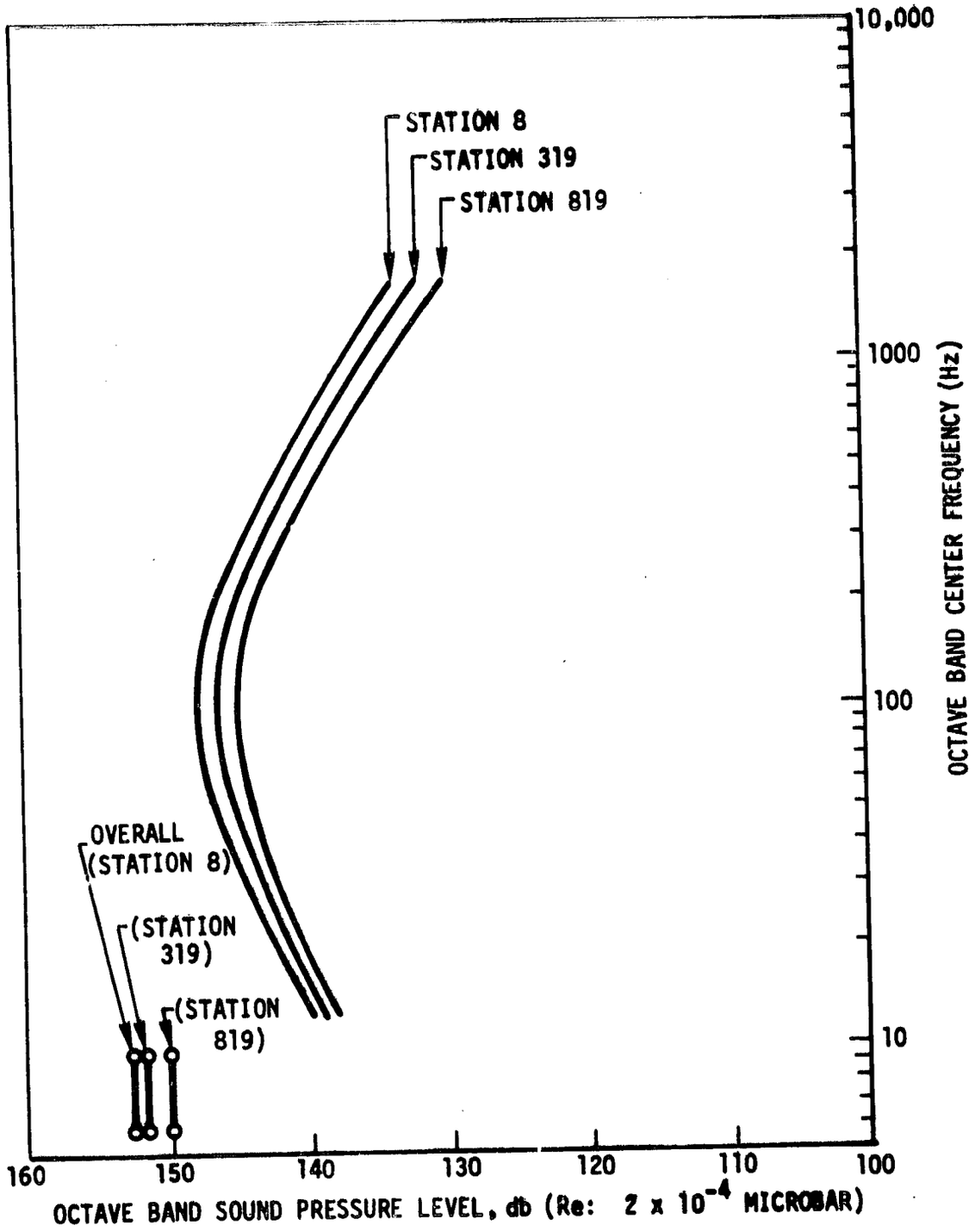


Figure 4.2.2.2-2. Maximum External Acoustic Environment for S-II Stage, Boost Flight Conditions

4.2.2.3 External Heating Distribution

The external heating distribution environment on a vehicle during transit through an atmosphere may consist of aerodynamic heating, separated flow heating, plume impingement heating, and base region heating. These environments will be discussed separately in the following paragraphs.

a. Aerodynamic Heating: The aerodynamic heating of a body moving through the atmosphere can be determined as a function of the atmosphere, the trajectory, the attitude of the vehicle, the winds within the atmosphere, and the shape of the vehicle. The problem of predicting the heating usually concerns the determination of the local Mach number outside the boundary layer, and the enthalpy of the gas media at the boundary layer edge and at the wall. The local pressure and local Mach number are found at a given atmospheric pressure, atmospheric temperature, vehicle velocity, and vehicle angle of attack (combining vehicle attitude, local velocity and local winds) either from correlated wind tunnel data or from theoretical calculations.

NASA has specified use of the 1963 Patrick Reference Atmosphere (Reference 9) and the Aerodynamic Heating Design Trajectory (NR Specification CP621M0014A). The design values of clean body heating rates for the LOR S-II stage are presented in NR Specification CP621M0014A, as are the multiplying factors to be used on the S-II stage protuberances and in the protuberance-influenced regions.

For flight evaluation for the S-II stage, actual values of atmospheric conditions, winds, and the trajectory may be used, together with digital computation programs, to predict the local pressure and local Mach number, and the aerodynamic heating. For other vehicles, the aerodynamic heating rate program may be used, together with values of local Mach number and local pressure. For other components of the Saturn V LOR vehicle, design heating rates have been presented (Reference 15). External insulation must accept the heating rates for various regions of application.

An example of the curves of heat transfer coefficient and recovery temperature as a function of flight time is presented in Figures 4.2.2.3-1 and -2. At any instant, the heat flux can be determined by using the equation

$$\dot{q} = h\,(Tr - Tw)$$

$\dot{q}$ = heat transfer rate, in Btu/ft^2 sec.

h = heat transfer coefficient, Btu/ft sec °R (Fig. 4.2.2.3-1)

Tr = recovery temperature, °R (Figure 4.2.2.3-2)

and where Tw = 540R, consistent with the values of h.

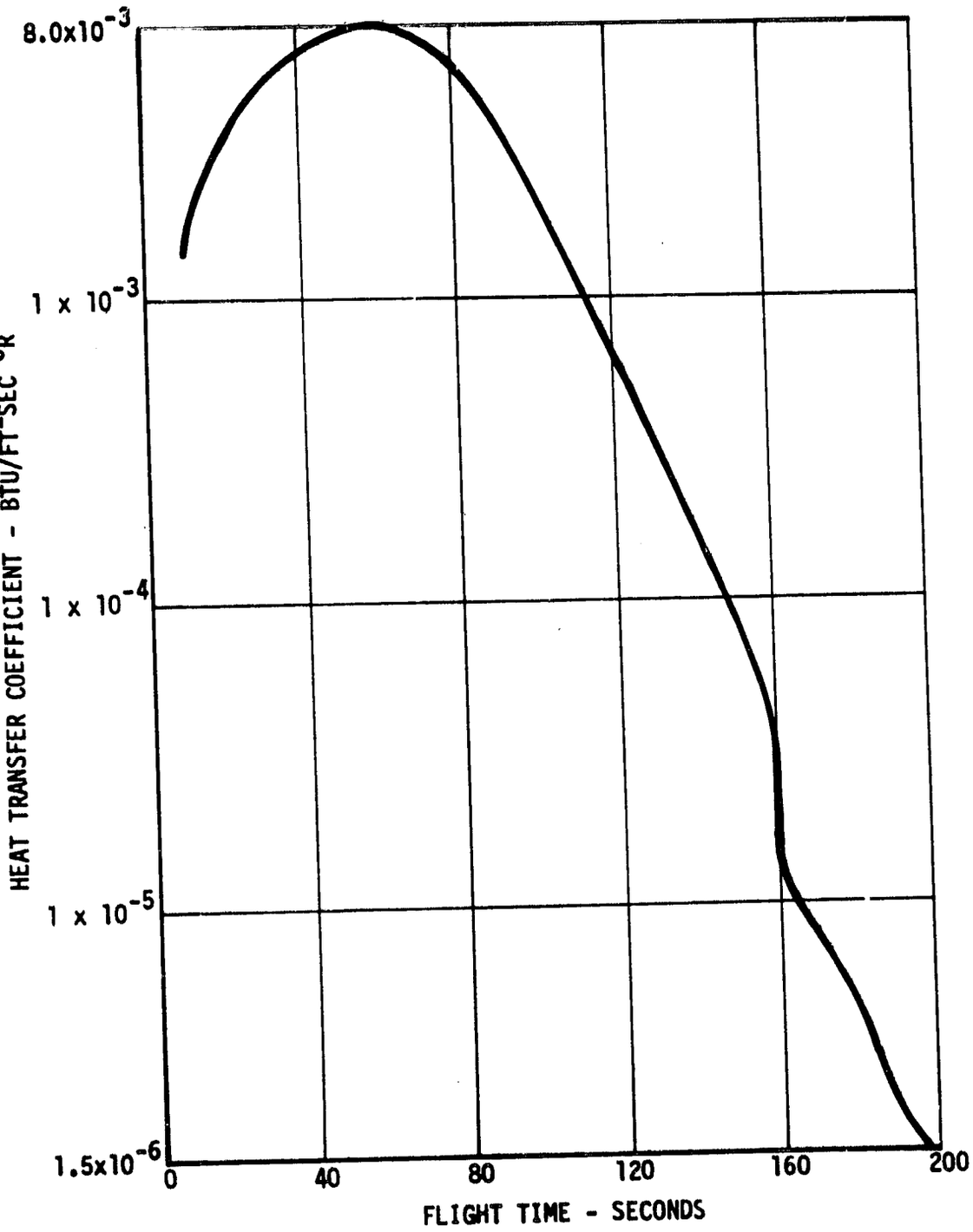


Figure 4.2.2.3-1. Clean-Body Aerodynamic Heating - Station 2405

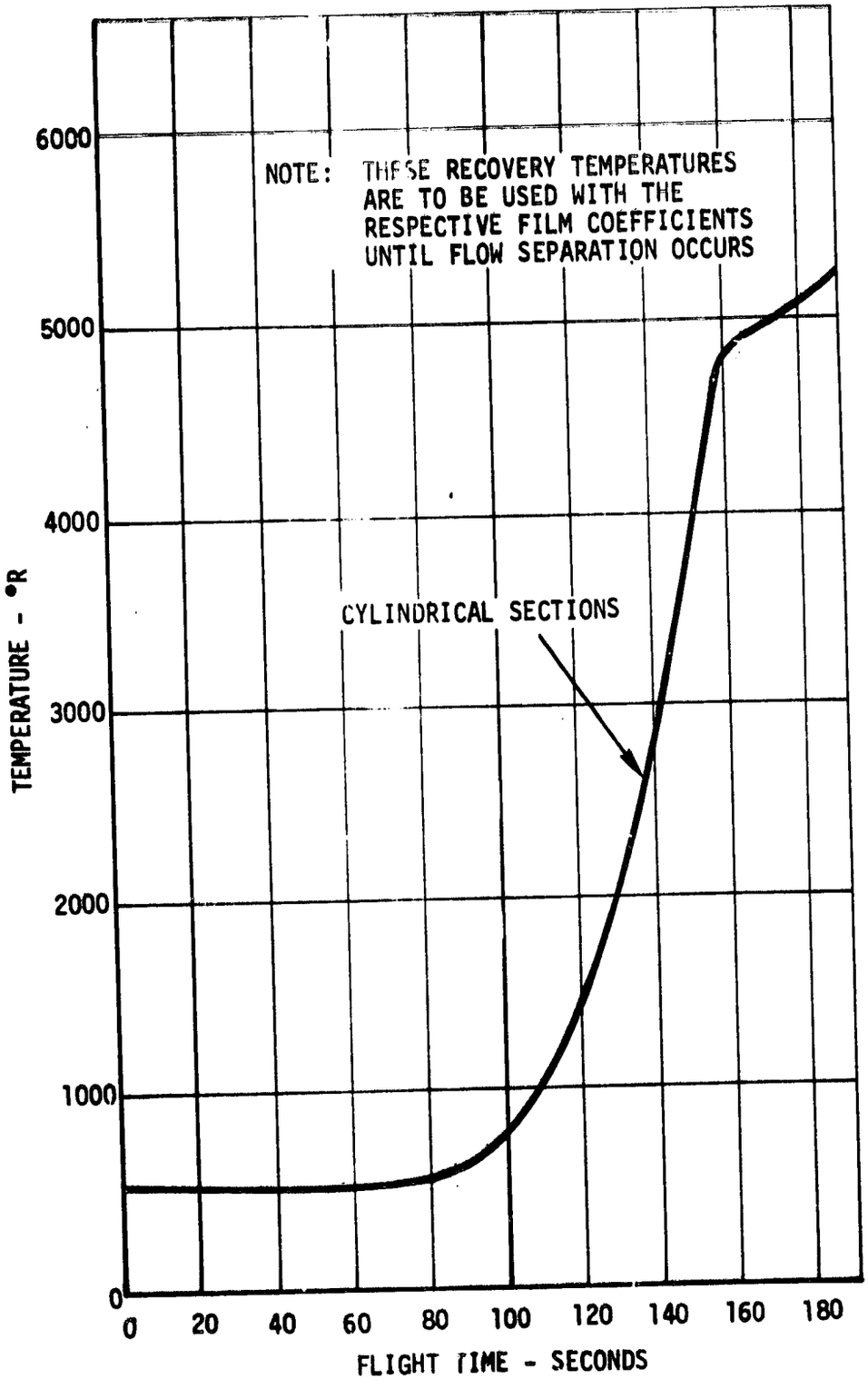


Figure 4.2.2.3-2. Recovery Temperature for Cylindrical Sections

It should be emphasized that the example curves are only valid for the specific configuration, atmosphere, trajectory, design winds, and location on the configuration, and should not be used for any other conditions.

The thermal design environment for Skylab has been presented (Reference 13). For configurations where two bodies are separated by gaps, great care must be exercised in analysis of the heating rates in regions where shock impingement occurs. It is possible to create shear layers, sudden transitions from laminar to turbulent flows, and similar complex flow field patterns wherein heating rates are increased greatly. Also, wing-body and tail-body regions can have sufficient interference heating regions. Lee-side vortex flow patterns can result in large increases in lee-side heating from that usually predicted. Heating rate wind tunnel tests are strongly recommended for any new flight configuration.

b. Separated Flow Heating: The mutual main engines plume impingement results in a base region pressure field which turns the flow down the stage away from the launch vehicle sidewall. The hot exhaust gases from the engines flow up to the sidewall to the point where the flow separates from the vehicle, then flow back toward the base region just inboard of the diverted flow. As this hot gas flows up the launch vehicle, it can enter the open downstream side of fairings over the systems tunnel, the various separation splices, the feedline fairings, and other openings with internal pressures less than that of the hot exhaust gas. The temperature rise of the materials within these fairings due to the separated flow heating was acceptable for the aerodynamic heating design trajectory of NR Specification CP621M0014A. However, using an NR prediction of separated flow heating, it was found that the ordnance and LH_2 pipes within the fairings required protection for the Skylab trajectory. As a result, the downstream ends of certain fairings were sealed to limit intrusion of the hot exhaust gases. Consideration must be given to intrusion of these hot gases between film layers when considering use of multi-layer insulation (MLI).

c. Plume Impingement Heating: The exhaust plume from an attitude control system rocket motor, an ullage motor, or a retrorocket motor will expand sufficiently at higher altitudes to impact the surface of adjacent structures. As this hot gas plume is turned by the structure, and flows along the surface, it heats the surface. During separation, the plume from an upper stage main engine may impinge on the lower stage surfaces. The heating rates to the surface are functions of the motor propellant constituents, mixture ratio, chamber pressure, nozzle exit/throat radius ratio, inclination of nozzle axis with respect to surface, nozzle exit distance from surface, surface curvature, surface protuberances, and position on surface. For main engine plume impact on lower stages, the relative separation, longitudinal and lateral, and the angular misalignment of the stages will all affect the heating distributions.

Plume impingement heating for the Saturn V LOR and Skylab missions and configuration have been published (References 13 and 15). A surface heating distribution for an RCS engine is presented in Figure 4.2.2.3-3. Insulation designed for protection from radiation in space may require protection from the RCS engine exhaust plumes.

d. Base Region Heating: The base region flow pattern leading to base region heating is discussed in paragraph 4.2.2.2d. As for base pressure, base heating cannot be predicted theoretically accurately enough for design purposes. Thus, base heating tests must be used for new configurations. The tests should encompass all the variables noted in Paragraph 4.2.2.2d. The S-IC base region heating for the LOR configuration and for Skylab has been documented (References 13 and 15).

   S-II heating rate distributions for the base region are presented in NR Report SID61-473-1.

4.2.2.4 External Shear Distribution

For this study, "shear" is considered as the force exerted on a surface, parallel to the surface, from the air stream, tending to remove the surface of the structure (or of surface insulation). The major sources of shear are the aerodynamic flow field over the vehicle and plume impingement shear. These two sources are discussed separately.

a. Aerodynamic Shear: Aerodynamic shear arises from the viscosity of the air. Close to the body, this viscosity manifests itself in the boundary layer. In this region, viscous forces are more important than pressure gradients in slowing the air to rest with respect to the launch vehicle, at the vehicle surface. The determination of the magnitude of the shear stress is made using the knowledge of the free-stream and of the local flow properties, and a boundary layer calculation. In general, the shear stress varies with the heating rates. A plot of shear stress versus spray foam surface temperature is presented as Figure 4.2.2.4-1. This figure was generated as part of an investigation of erosion of spray foam, and is for the basic sidewall of the S-II stage for the design aeroheating trajectory. Higher shear stresses would be experienced in protuberance-influenced regions, as shown in Figure 4.2.2.4-2.

   In addition to boundary layer shear stress, certain types of insulation could have a backwards facing step at the rear of an insulation segment, or a forward facing step at the front of the segment. The forces on an insulation panel, due to these steps, can be combined with the boundary layer shear stress to develop an equivalent shear stress, tending to remove insulation material or panels.

b. Plume Impingement Shear: A shear stress is also generated by plume impingement flow on a surface. In general, due to the assumptions involved in calculating plume impingement heating, a simple relation (Reynolds' analogy, Reference 27) is used to calculate shear stress from the heat transfer coefficient.

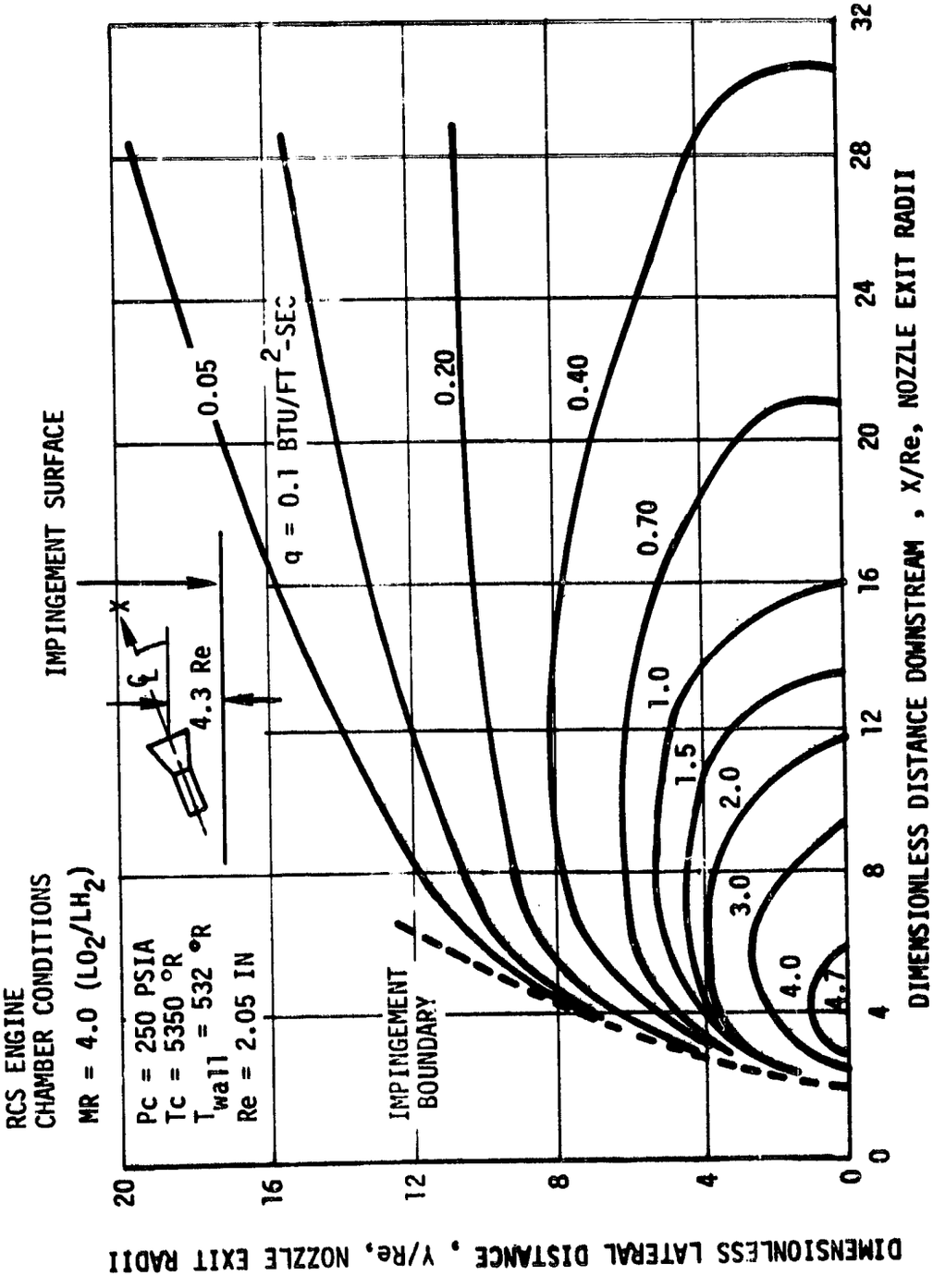


Figure 4.2.2.3-3. RCS Plume Impingement Heating Rates

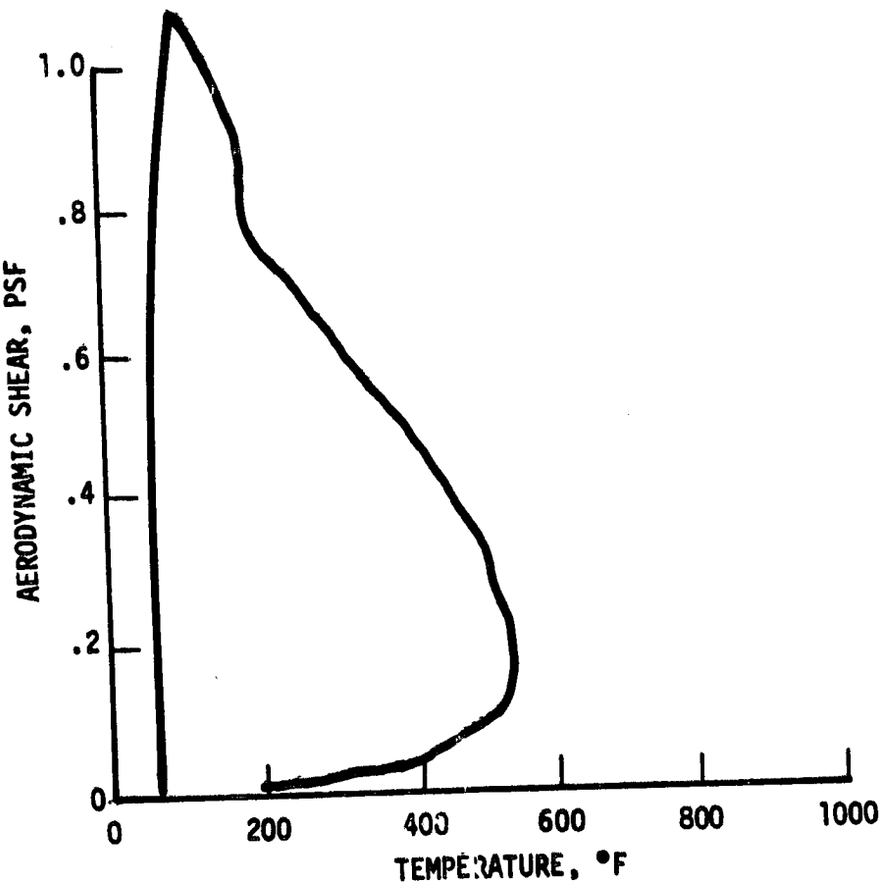


Figure 4.2.2.4-1. Shear-Temperature History for S-II Stage Spray Foam Away From Protuberance

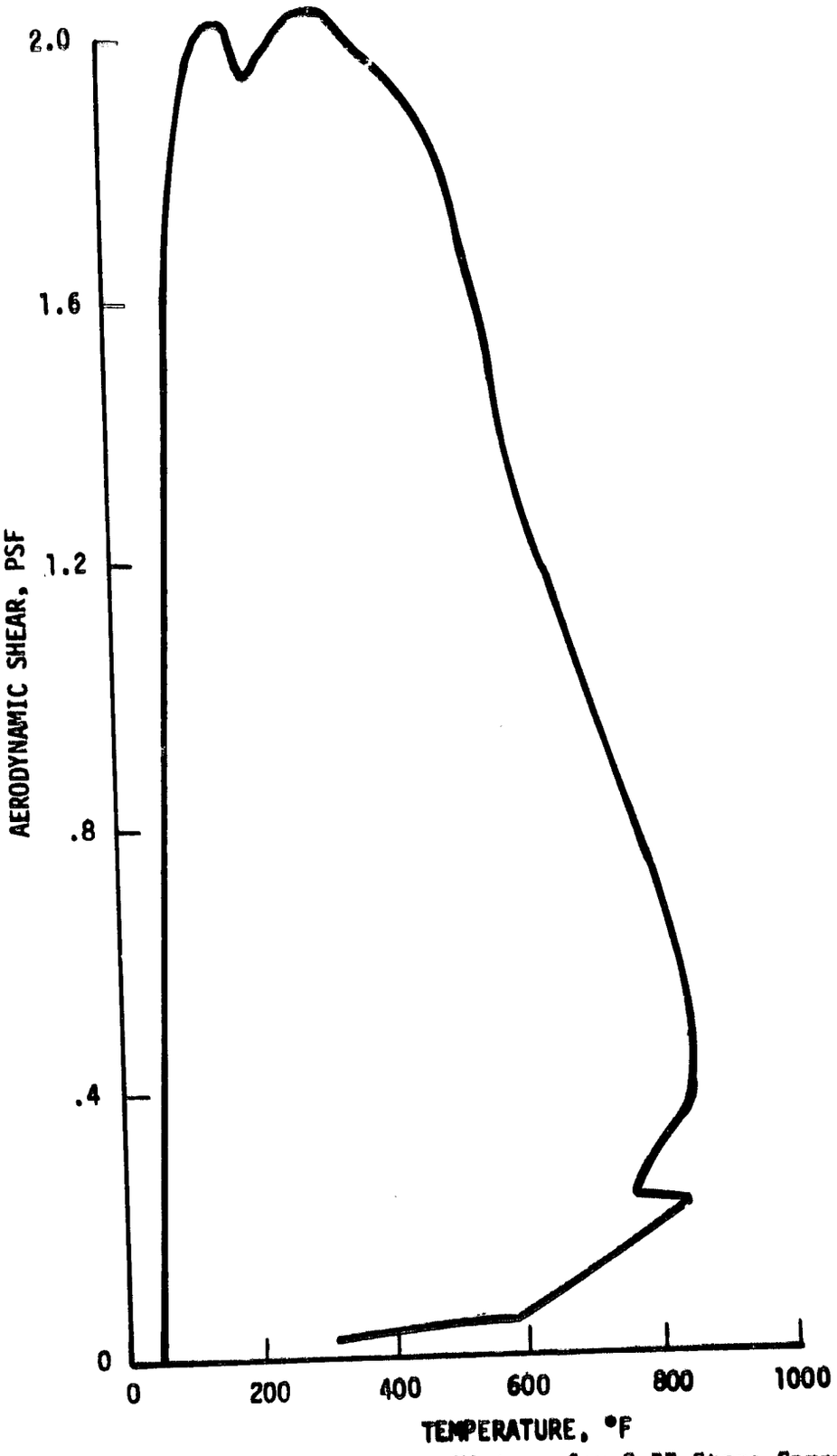


Figure 4.2.2.4-2. Shear-Temperature History for S-II Stage Spray Foam in Maximum Protuberance-Influenced Regions

4.2.2.5 Insulation Venting

At lift-off, most types of insulation (except vacuum jacketed tanks, for example) contain air or a purge gas at or slightly above atmospheric pressure. As the launch vehicle boosts towards higher altitudes and the external pressure decreases, this gas must be vented to prevent damaging levels of differential pressure across facing sheets, or across insulation layers. In addition, space insulation of the MLI type, or of the REI type, has better insulation quality if the convective heat transfer through the gas, initially within the insulation, is reduced by reducing the gas pressure.

The NR Multiple Chamber Venting Program YI0013 contains an assumption that the gas flows from rigid fully open compartments through pipes or orifices to other compartments, and thus to the outside of the launch vehicle.

This program was used to predict the time required for the S-II-1 stage helium-purged sidewall cryogenic insulation internal pressure to drop to atmospheric pressure levels during a blowdown test. The actual time was longer than the predicted time.

It was suspected that the adhesive partially blocked the passageways through which the gas flows. Parts of the flow passage from the insulation to the gas manifolds may also have been blocked. In order to keep the facing sheet intact, additional flow passages were opened.

From this experience, it was learned that provision must be made for determining an effective open area for orifices, to compensate for the partial blockage of gas passages. The values of effective area must be obtained from test data, together with use of the venting program. Parameters are varied until the experimental blowdown pressure-time history and the predicted curves of pressure-time history agree.

The prediction of the venting of MLI or REI to pressure levels of 10^{-4} Torr, or lower, is a complex task. The basic type of gas flow within the insulation changes from continuum to transitional to free molecular flow (Reference 25). The gases evolved from the MLI layers, or within the interstices of the REI, form an important part of the gas load, delaying achievement of the desired low pressures. The gases evolved depend heavily on the history of the material, previous pumpdown cycles, temperature, and on the composition of the purge gases. Again, the insulation should be subjected to a typical duty cycle, and measurements made of pumpdown pressure-time history.

4.2.3 Earth Orbital Environment

In addition to the natural environment at orbital altitudes, a structure (e.g., insulation) is subject to an induced pressure and heating environment which varies with orbital altitude, as well as a plume impingement environment. These environments will be discussed in the following paragraphs.

4.2.3.1 Plume Impingement Environment

At earth orbital altitudes, the plume from a nozzle spreads to a much greater degree than when constrained by the more dense atmosphere at lower altitudes. Thus, the plume may envelop the stage. If the insulation has been venting for a significant period of time prior to the burst of gas from the plume, there will be a pressure gradient driving the gas into the insulation. The same effects, including increased convective heating, would occur at orbital altitudes as discussed previously in Paragraphs 4.2.2.2b, 4.2.2.3c, and 4.2.2.4b.

4.2.3.2 External Pressure Environment

In addition to the self-generated atmosphere of an aerospace vehicle, caused by the outgassing of structural components and of insulation, leakage from internal spaces, overboard discharge of wastes, etc., there is a tenuous atmosphere at earth orbital altitudes. Since the aerospace vehicle is traveling at very high velocities, there will be a pressure force exerted on external surfaces of the vehicle. The force will depend on the surface orientation (Reference 26) with respect to vehicle velocity vector, vehicle configuration, surface material, temperature, coatings, and the natural environment at the orbital altitude. The natural environment will also vary with solar flares; for example, under such a variety of parameters, the prediction of pressure distribution is a complex problem. At the higher orbital altitudes, 100 nautical miles and higher, the main influence on insulation would be the effect on venting of the MLI.

4.2.3.3 External Heating Environment

The overall heating of the aerospace vehicle in earth orbit is primarily due to solar radiation, either direct or reflected from the earth, depending on orbital parameters. This heating would be considered as natural environment.

The passage of the vehicle at very high speed through the tenuous atmosphere results in heating of the body due to molecular impact at very high altitudes (Reference 25). The factors which affect pressure (see Paragraph 4.2.3.2) also affect heating. Concavities and holes pointing in the direction of travel tend to concentrate the molecules into a smaller area and increase the heating rates locally, and thus should be avoided.

5.0 DESIGN REQUIREMENTS

5.0 DESIGN REQUIREMENTS

5.1 INTRODUCTION

The principal purpose of a passive insulation system is to provide protection for specific vehicle subsystems that are sensitive to external heat. The required protection is different for each subsystem with respect to type, degree, time, and duration. The natural and induced environments to which they are exposed also vary. Each of these variables represents a constraint or requirement which affects the physical design of the insulation system. This relationship is shown in Figure 5.1-1. It is the purpose of this section to identify the sources of design requirements and to show relationship of requirements to system design. Table 5.1-1 is a checklist of requirement considerations.

Protected subsystems include:

a. Propellant subsystems require thermal protection to insure the required quantity of propellant will be available at the proper quality each time the engines start and throughout each burn.

b. The structural subsystem requires that the temperature of the primary structure be kept below design limits during periods of critical loading.

c. The pressurization subsystem requires that heat be retained within a given ullage volume to insure maintenance of pressure control, or that heat be excluded from a given storage volume to preclude overpressurization of the volume.

Environments include the following:

a. Natural environments include those stimuli that a system experiences due to natural local climate. Terrestrial stimuli varies with geographic location, time of year, and time of day. Space environment varies according to location in space and attitude.

b. Induced environments include the dynamic effects imposed by flight through the atmosphere and the effects imposed by radiation or conduction from adjacent system boundaries.

Contractual documents will define program end objectives. Generally this will require delivery of a given payload from a given location and along a given trajectory under given launch conditions. Insulation system design requirements evolve and are definitized through an iterative, coordinated process involving a number of interfacing disciplines and subsystems.

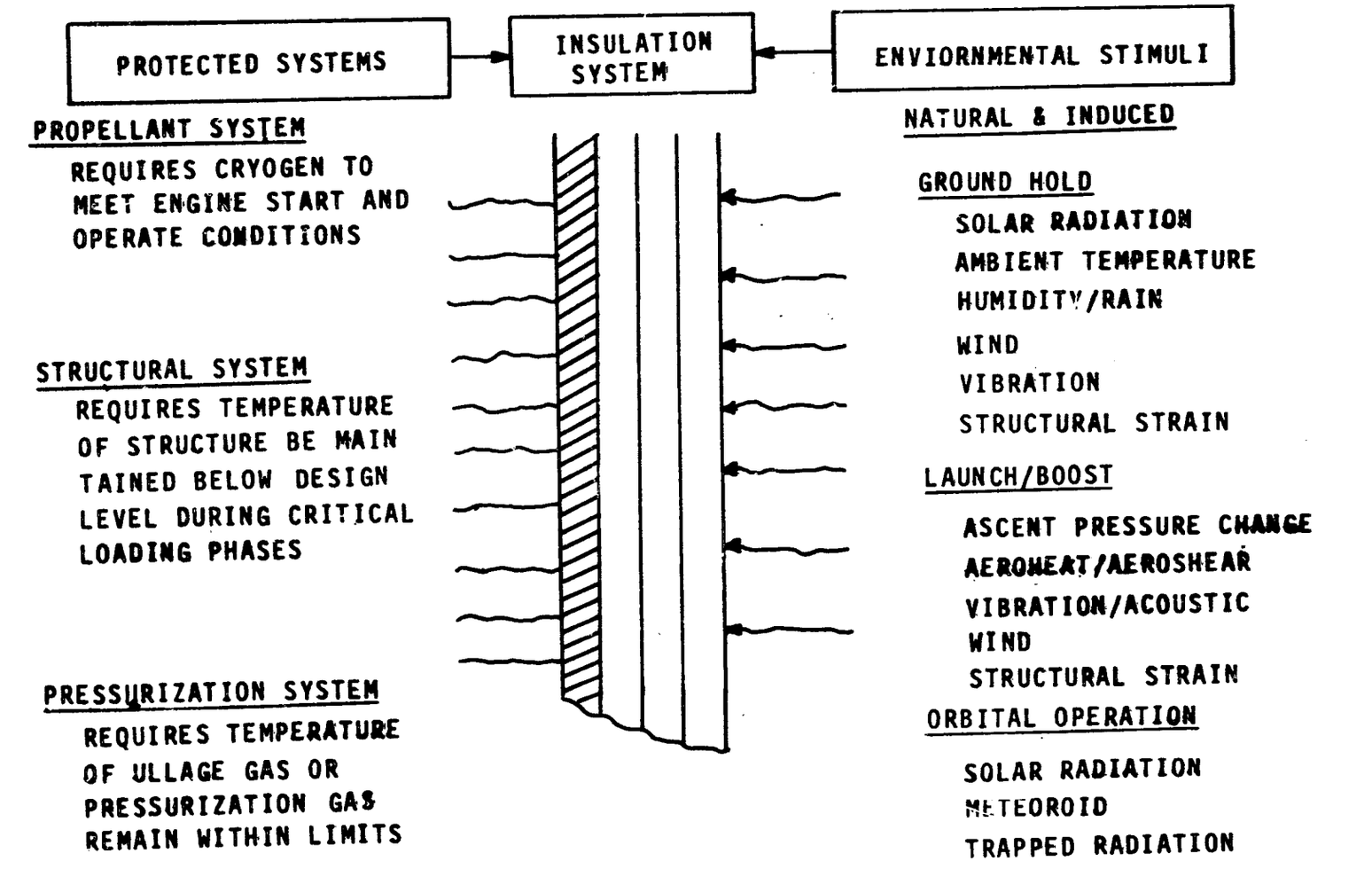


Figure 5.1-1. Insulation System Design Requirements

Space Division
North American Rockwell

Table 5.1-1. Requirement Consideration Checklist

Area	Considerations
Propellant System	Temperature Pressure Time
Pressurization System	Temperature Pressure Time
Structural System	Pressure Temperature Strain Loads
Aerodynamic	Acoustic/Vibration Pressure Temperature Drag
Terrestrial Environment	Thermal Radiation Temperature Humidity Precipitation Rain Snow Hail Wind Ground Inflight Abraision Sand and Dust Snow Raindrops Hail Atmospheric Pressure/density Electricity Corrosion Oxidants Fungus and Bacteria
Space Environment	Gas Radiation Meteroid Geomagnetic Astro-dynamic

5.2 SOURCES OF DESIGN REQUIREMENTS

The influence of interfacing subsystems on insulation system design requirements is described in this section.

The insulation system must perform thermally during cryogenic tests on the ground as well as in flight; it must withstand the structural maneuvering associated with transportation, installation, and flight; and it cannot deteriorate itself or contribute to vehicle deterioration during long storage periods. Each of these phases exert significant and different requirements which must be incorporated into the design. The general procedure is to design the system to the most severe requirement — generally the flight phase — and then check its adequacy against requirements for the other phases. Detail design requirements are presented in Section 5.3.

5.2.1 Thermal Performance Requirements

The principal objective of the insulation system is to limit heat input to the cryogen both on the ground and in flight. This maintains the cryogen in the liquid state and in condition acceptable for engine operation. The acceptability (quality) of the cryogen is defined in terms of temperature and pressure at key operational or commit times as shown in Figure 5.2.1-1.

5.2.1.1 Ground Hold Operations

During ground hold operations with cryogen loaded, heat passes through the insulation into the cryogen which results in increased bulk temperature or loss of the cryogen through boiloff. The lost propellant must be replaced by topping operations which represent an important element in facility layout and logistics.

The GH_2 which is boiled off is vented by a pressure-controlled valve into a facility discharge line that is common to all stages. It flows to a remote location where it is safely burned. The venting pressure is kept as low as possible (approximately 1.5 psig) to minimize the bulk heating consideration. Sporadic venting, however, disturbs the thermal equilibrium of interfacing vehicles which, in turn, can delay launch countdown timing.

The size of the vent valves and the back pressure in the facility lines and burn pad represent constraints on the thermal performance requirement for the installed insulation system. On the S-II program, a requirement was established initially by NASA that the insulation system limit LH_2 boiloff to less than 6 percent per hour of full tank load (NR Report SD-11-67-32). This was subsequently changed to relate venting pressure of 16.2 psia with performance requirement shown in Figure 5.2.1-1 (CP621M0014A). This currently represents a good initial target requirement for launch vehicles utilizing the same facility.

NOTE: MAINSTAGE VALVES ARE APPLICABLE FOR THE TIME PERIOD STARTING 3.0 SECONDS AFTER START TANK DISCHARGE VALVES (STDV) CONTROL SIGNAL

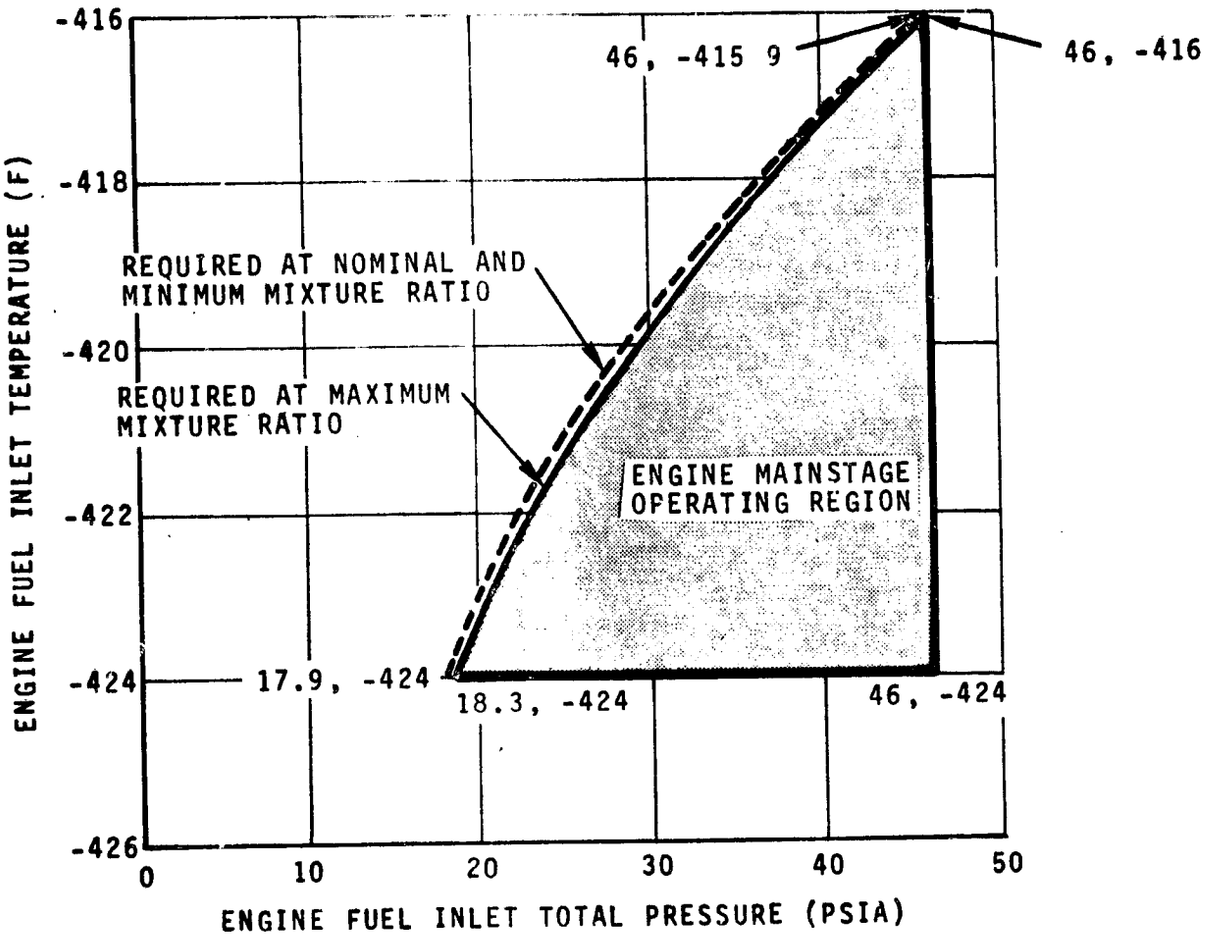


Figure 5.2.1-1. Mainstage Engine Fuel Inlet Requirements

Other programs may impose more severe requirements; for example, vehicles with space missions may require that the exterior surface temperature of the insulation be warm enough to preclude condensation of moisture during prelaunch holds. A requirement of this nature will influence requirements of insulation thickness and purging.

5.2.1.2 Flight Performance

Generally, flight performance requirements will influence the system design to greater degree than ground hold requirements. These requirements are determined by the heating that can be accepted by the propellants from the time of final topping on the ground until final engine shutdown in flight. For a launch vehicle or a vehicle whose mission requires only one engine firing, this requirement is normally

expressed as total Btu's per mission. For the S-II stage, this was initially set at 215,000 Btu (NR Report SD-11-67-32), but subsequently revised to 183,000 Btu.

It is important to note that thermal performance requirements for launch phase must consider the effects of profile time. Aeroheating occurs during flight through sensible atmosphere but falls off rapidly after maximum dynamic pressure condition is experienced. The insulation surface temperature will vary accordingly. Also, insulation system requirements may be established to allow the insulation system to absorb heat during this time without transferring it into the primary tank until after the cryogen has been used.

The thermal performance requirement in space vehicles is established from the allowable cryogen boiloff. This is generally defined as percentage of initial tank load and loss is limited to a given period of operation. For short missions it can be assumed that all heat input results in loss of cryogen through boiloff. Longer missions must take change in cryogen quality into account for optimum insulation design. A typical requirement for an application of this type limits boiloff to 1.15 percent of full tank load for seven-day mission. For vehicles in the space environment, thermal performance requirements generally provide that the total charged weight of the insulation system plus total boiloff weight be minimized. Figure 5.2.1.2-1 shows this effect on optimization of insulation thickness.

5.2.1.3 Structural Temperature

On the S-II stage, the primary structure is in essence a large tank containing LH_2 under pressure. The tank accepts the thrust loads from the first stage (S-IC) and transmit them to the third stage (S-IVB). In order to accomplish this with minimum stage weight, the tank skin was maintained at cryogenic temperature, thereby taking advantage of higher mechanical properties. A strength increase of 35 percent was realized at -423 F with a 2500-pound weight saving. This required that the insulation be applied to the outside of the tank (NR Report SD 68-125).

Other applications may require that the insulation maintain the structure at temperatures nearer ambient (e.g., the S-IVB stage) and this requires insulation to be located on the inside of the tank. An overview of this problem can be obtained in Reference 16.

5.2.2 Structural Requirements

Bonding of organic insulation to the metal structure causes a series of structural requirements to be established for the insulation itself which influences selection of materials and installation procedures. When the tank wall is cooled to cryogenic temperature, it contracts biaxially. The organic material adjacent to it attempts to contract more than the aluminum but is constrained by the metal which has a much

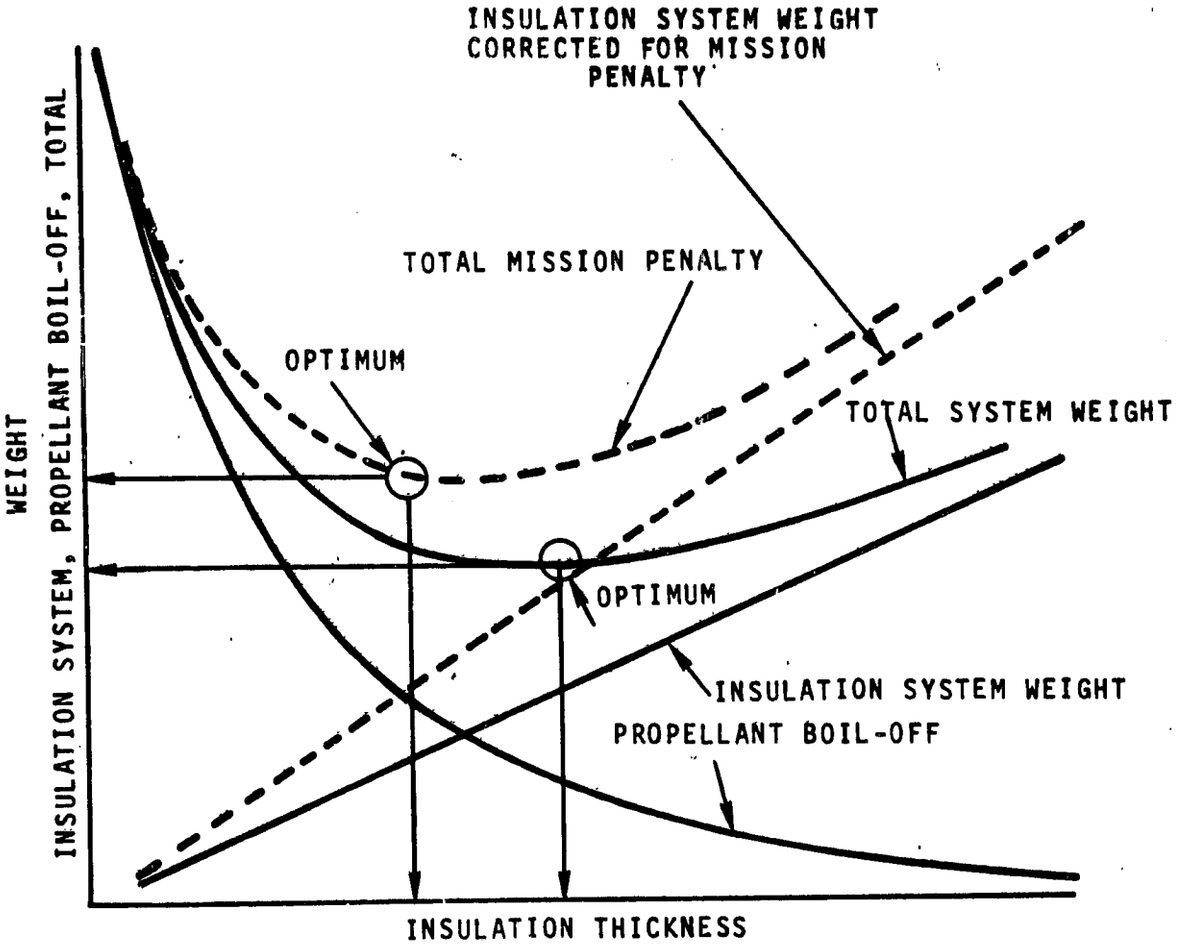


Figure 5.2.1.2-1. Optimization of Insulation System

larger modulus of elasticity; therefore, thermal strains are induced in the organic material at the interface with the tank wall. This strain is increased when the tank is pressurized or when the surface temperature of the insulation increases. A design requirement is established to identify the strain so that structural integrity may be insured. Typically, an interface capable of withstanding strains of 0.0044 inches per inch of interface length is required.

Additional insulation system structural requirements exist where the insulation is purged or where it is subject to external pressures due to venting during flight. These requirements originate from aerodynamic pressure environments and influence the size of venting apertures, internal purge passages, and purge volumes. As previously stated, it is important to identify the relationship between altitude,

pressure, and surface temperatures on a time basis when establishing these requirements. To do otherwise may result in overdesign. For example, as seen in Figure 5.2.2-1, maximum pressure and temperature do not occur simultaneously and to design for that case would impose unnecessary weight, cost, and complexity to the system.

For the case of vehicles with space missions, the structural requirements which relate to pressure differentials across the insulation generally also affect the thermal performance requirement. For example, a structural requirement may exist for a system utilizing multi-layer insulation. However, the gas pressure which creates the structural load also affects thermal performance and additional requirements may be necessary to insure venting of the gas within a given time.

Another requirement is important that the insulation structural integrity does not deteriorate due to time. This is particularly necessary for insulation systems which are adhesively bonded or otherwise structured. In addition, requirements are developed to insure that the insulation system does not contribute to corrosion of the metal structure below it. These requirements influence the selection of materials, storage, installation procedures, and auxiliary supporting systems.

5.2.3 Operational Requirements

This class of requirements are imposed because of the manufacturing, transportation, test, and storage phases of the vehicle life. Generally, these operations represent more severe conditions than are experienced in flight. Requirements in these phases must be carefully established to insure that adequate but not excessive restrictions are imposed.

As an example, a vehicle such as S-II that undergoes cryogenic testing in a holddown stand is not subjected to the same structural loads, acoustic/vibration environment, or periods of operational exposure as when assembled into the launch configuration. Where these conditions are found to be different than the launch phase, requirements are developed to insure design adequacy.

5.2.4 Environmental Requirements

The criteria for environmental requirements are generally obtained from guidelines established by NASA. These are imposed on the basis of geographical location of the application and exert great influence on selection of materials, design configurations, and storage conditions.

References 17 and 18 are the sources of requirements for terrestrial climatic criteria and References 19, 29, and 30 are sources for space environment criteria.

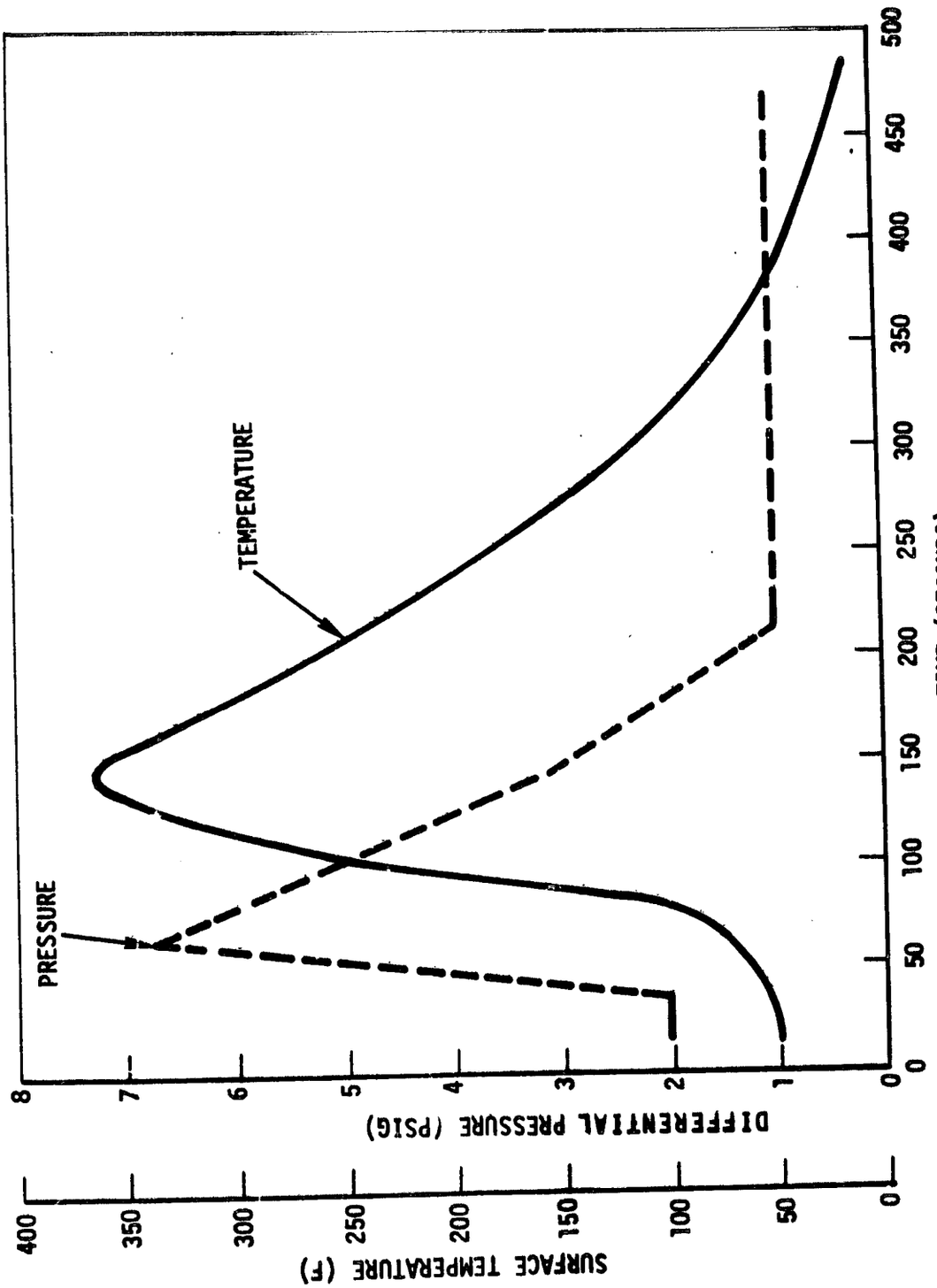


Figure 5.2.2-1. Temperature and Differential Pressure Profiles

5.3 DETAIL SYSTEM DESIGN REQUIREMENTS AND RESULTANT PERFORMANCE

Insulation systems were designed to the detail requirements presented in this section. The purged honeycomb base configuration was incorporated on stages S-II-1 through S-II-7. A foam configuration was utilized on S-II-8 and subsequent stages. High-performance insulation was the subject of an advanced application study.

5.3.1 Propellant Tanks

S-II initial contractual specifications required that "the insulation for the liquid hydrogen tank shell and forward bulkhead shall be designed to a thickness compatible with the design criteria and mission requirements established for the S-II stage." Subsequent developments in the influence of changing subsystem requirements produced changes in these specifications. The key specification requirements as developed are presented in this section.

5.3.1.1 Honeycomb Base System

Key contractual requirements for this system required the following design:

a. Limit the heat input to the LH_2 so that J-2 engine pump net positive suction head (NPSH) requirements are met.

b. Heat input consistent with a 16.2 psia maximum vapor pressure during ground hold.

c. The total heating mission time is from initiation of tank pressurization to end of S-II boost.

d. The insulation must be capable of withstanding stresses induced by virtue of its attachment to the primary structure in combination with stresses resulting from natural and induced environments and the aerodynamic thermal environment.

e. The insulation will be designed to provide for the detection of excessive structural leakage of hydrogen by a ground facility detector.

f. Insulation and other required areas will be purged during ground operations with purge gas furnished from a ground facility.

To meet these specifications, three basic design requirements were imposed: (1) boiloff during ground hold must not exceed 6 percent of tanked volume; (2) total heat input to LH_2 in flight must not exceed 209,000 Btu; and (3) the insulation must be external to the primary

structure and incorporate a purge system which also will be used for leak detection.

a. Detail Design Requirements:

1. Surface temperature in flight as shown in Figure 5.2.2-1.

2. System pressure differential in flight as shown in Figure 5.2.2-1.

3. The separate purged insulation systems must meet the following pressure, flow, and leak requirements following final assembly:

System	Test	Pressure (psig) Inlet	Outlet	Flow (scfm)	Leak (scfm)
Forward bulkhead	Proof	6.0	6.0	-	-
	Gross leak	3.0	-	-	1.0
	Flow	4.0	0.5	2.0	-
Forward skirt	Proof	1.5	1.5	-	-
	Gross leak	1.0	-	-	1.0
Sidewall	Proof	7.0	7.0	-	-
	Gross leak	4.0	-	-	1.0
	Purge flow	3.0	-	-	3.5
Cylinder 1	Proof	2.8	-	-	-
	Gross leak	2.7	-	-	1.2

4. The environment to which the insulation system will be exposed is defined in Paragraph 3.1.2.4 of CP621M0014A. Table 4.1.1-1 is an extract from that reference and summarizes the climatic extremes of natural environment.

5. The insulation system must withstand strains imposed by the primary structure when the structure is subjected to equivalent uniaxial stress of 55,000 psi while at a temperature of -423 F. This is equivalent to strain of 0.0044 in./in.

6. The insulation system and associated primer and bonding system shall protect the stage structure against corrosion from self-induced or catalyzed causes.

b. Configuration: The insulation system selected on the basis of the preceding requirements is shown in Figure 5.3.1.1-1 and detailed design is presented in Paragraph 6.1.1.

c. Performance: Performance of the purged base system was well within the requirements previously presented.

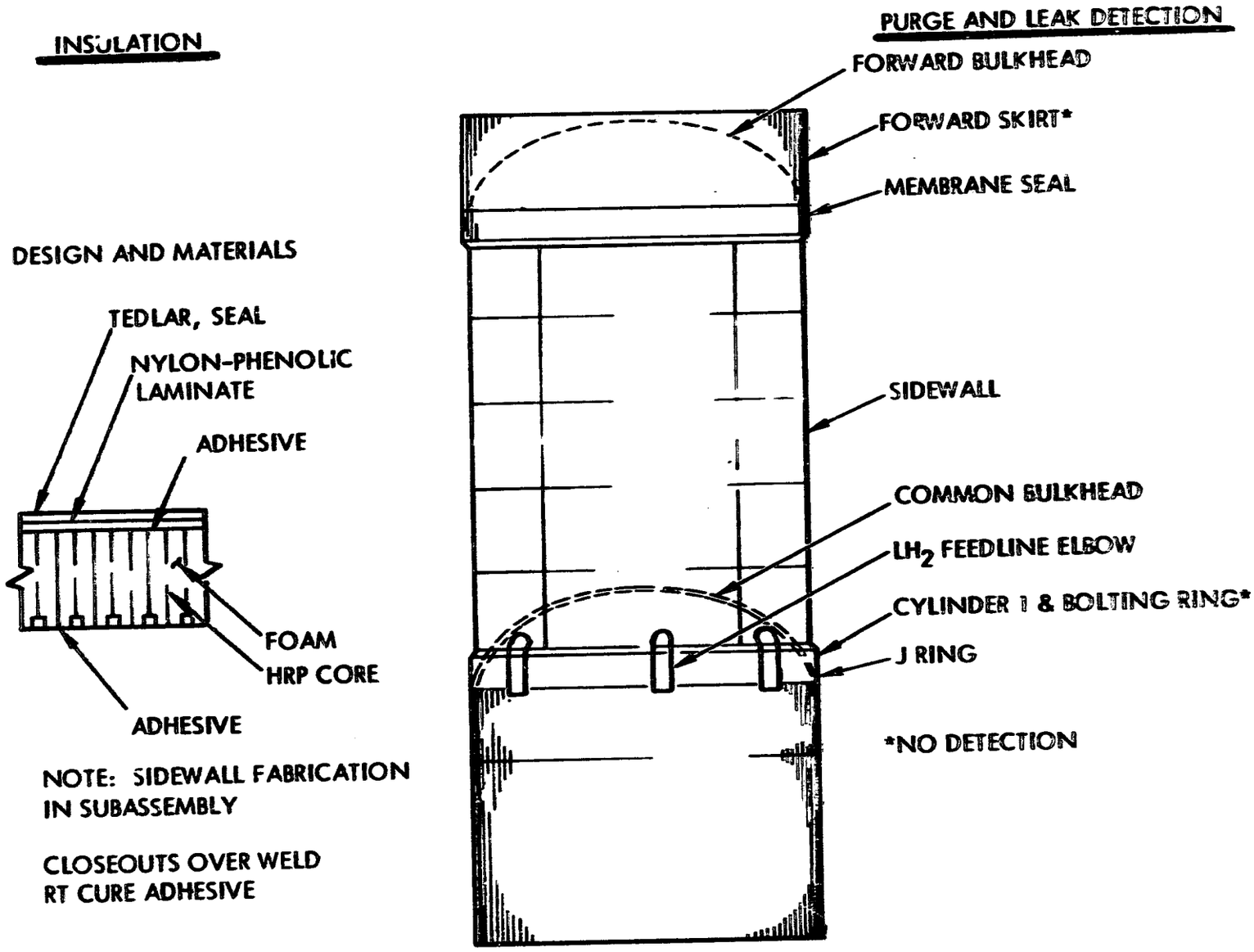


Figure 5.3.1.1-1. Subsystem Description

1. Ground boiloff: Measurement of LH_2 boiloff was 110 pounds per minute which is equivalent to 4.2 percent per hour.

2. Heat transfer to the LH_2 is shown in Figure 5.3.1.1-2 for the AS-504 launch. Heat transfer during other launches varied from 130,000 Btu to 171,000 Btu.

3. Surface temperatures experienced during flight of the first four S-II stages are shown in Figures 5.3.1.1-4, -5, -6 for the locations shown in Figure 5.3.1.1-3.

5.3.1.2 Foam System

Demonstration of the reliability of the primary structural system on the S-II stage permitted deletion of the structural system leak detection requirement. The purged honeycomb system which incorporated the leak detection capability was then replaced by a sprayed-on polyurethane foam insulation which met the primary thermal performance requirements and reduced stage weight by approximately 2500 pounds.

a. Detail Design Requirements:

   1. Structural Strains: The foam/primer system must withstand strains imposed by the primary structure when it is subjected to equivalent uniaxial strain of 0.0044 in./in. while at -423 F.

   2. Corrosion Protection: The foam and any associated primer system must protect the stage structure against corrosion from self-induced or catalyzed sources.

   3. Coatings: A coating is applied to the exterior of the insulation to maintain a white color and exhibit flame-retardant or self-extinguishing characteristics. It must exhibit no ballooning and minimum debris when subjected to aerodynamic heating and shear.

   4. Thermal-Altitude Profile: As shown in Figure 5.3.1.2-1.

   5. Flammability: The foam material must be flame-retardant to reduce the fire hazards associated with the use of liquid hydrogen and liquid oxygen propellants.

b. Configuration: The insulation system configuration selected to meet these requirements is shown in Figure 5.3.1.1-2 and design details are presented in Paragraph 6.1.4.

c. Performance: Performance of foam insulation system was well within design requirements. Table 5.3.1.2-2 shows a comparison of the first two stages incorporating this system (S-II-8 and -9) with key performance parameters and with performance of honeycomb base systems.

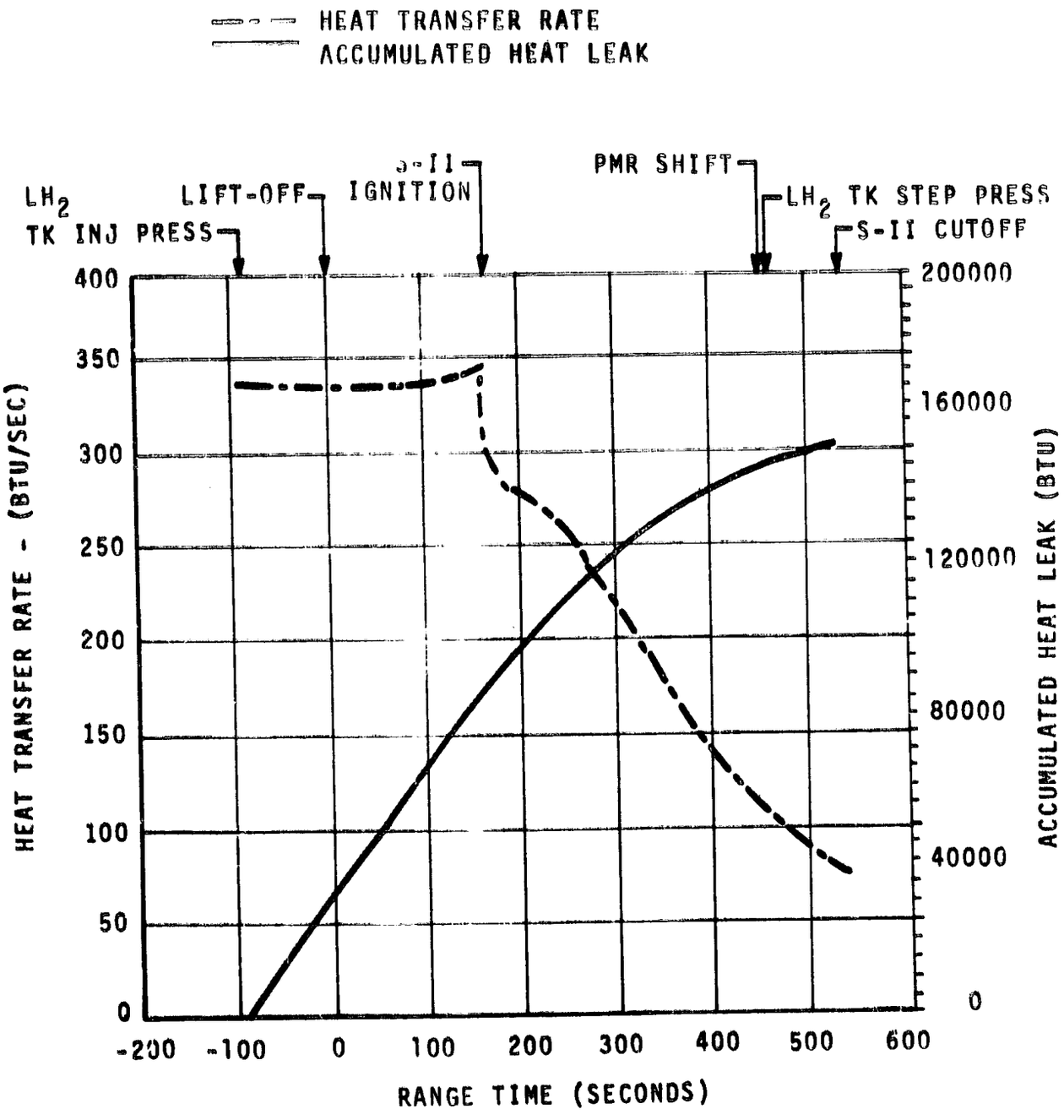


Figure 5.3.1.1-2. Heat Transfer to Onboard LH_2 - AS-504 Flight

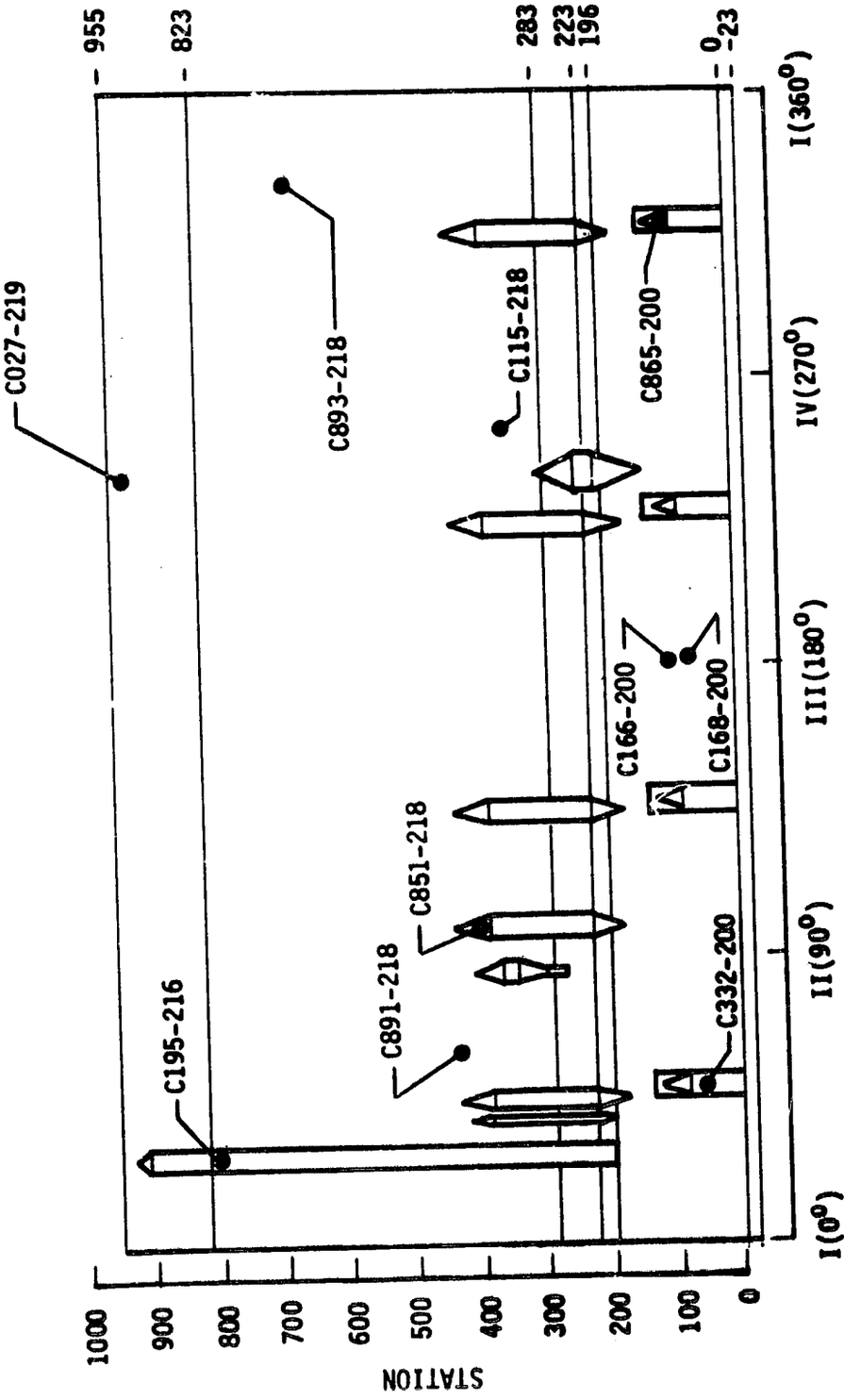


Figure 5.3.1.1-3. Aerodynamic Heating Structural Temperature Measurement Locations

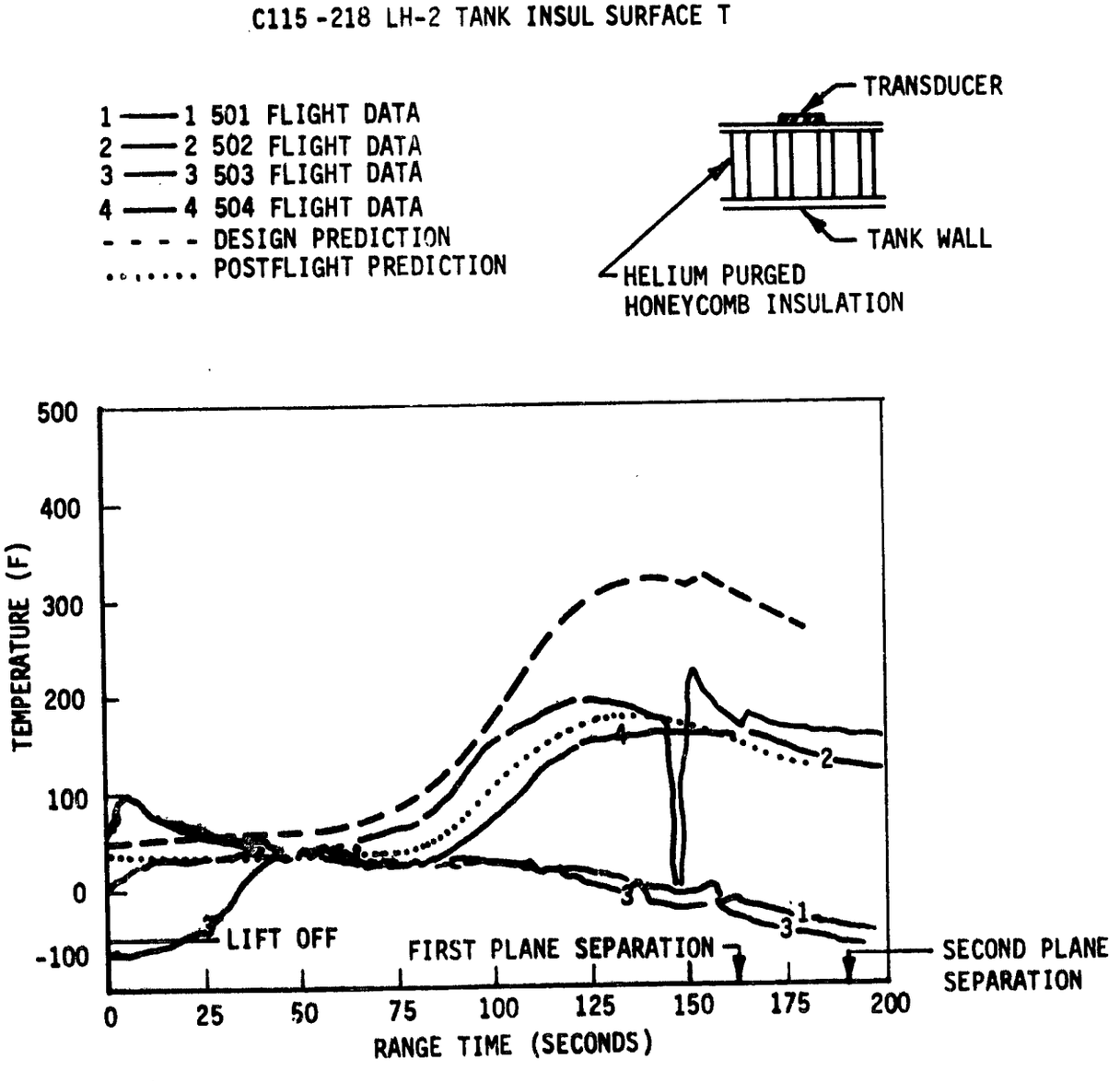


Figure 5.3.1.1-4. Saturn V Flight AS-504

C891-218 LH-2 TANK INSUL SURFACE T

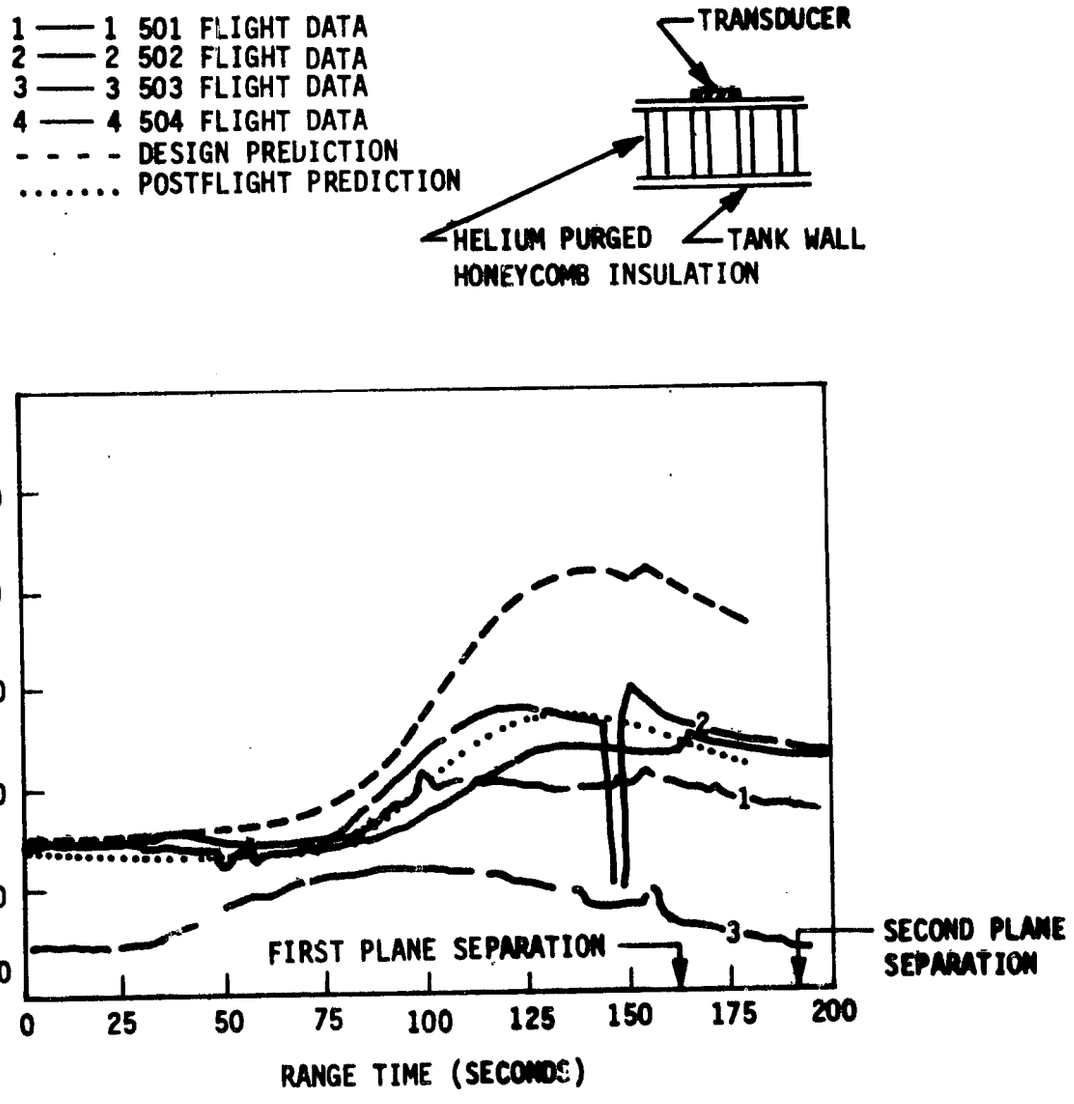


Figure 5.3.1.1-5. Saturn V Flight AS-504

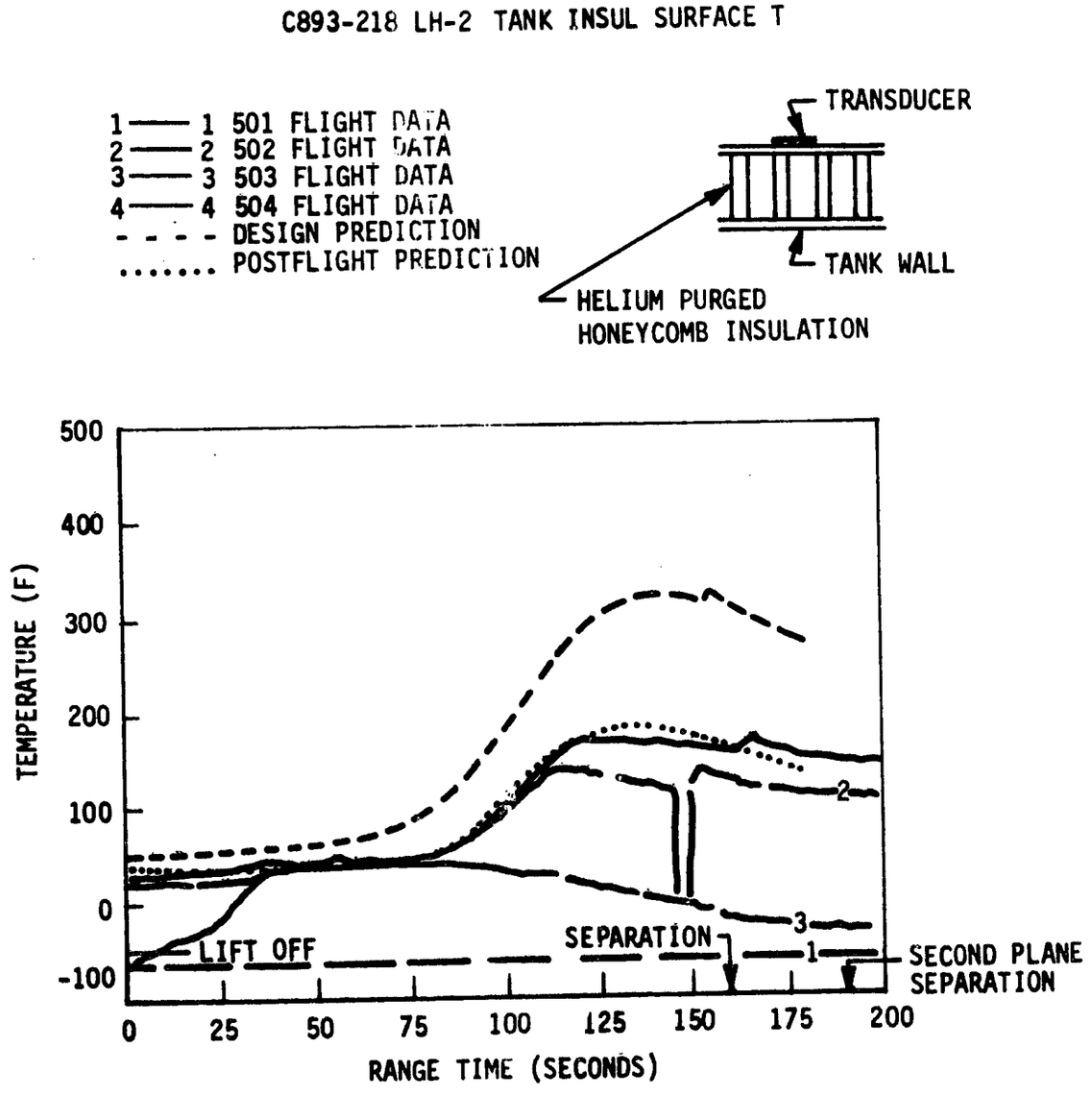


Figure 5.3.1.1-6. Saturn V Flight AS-504

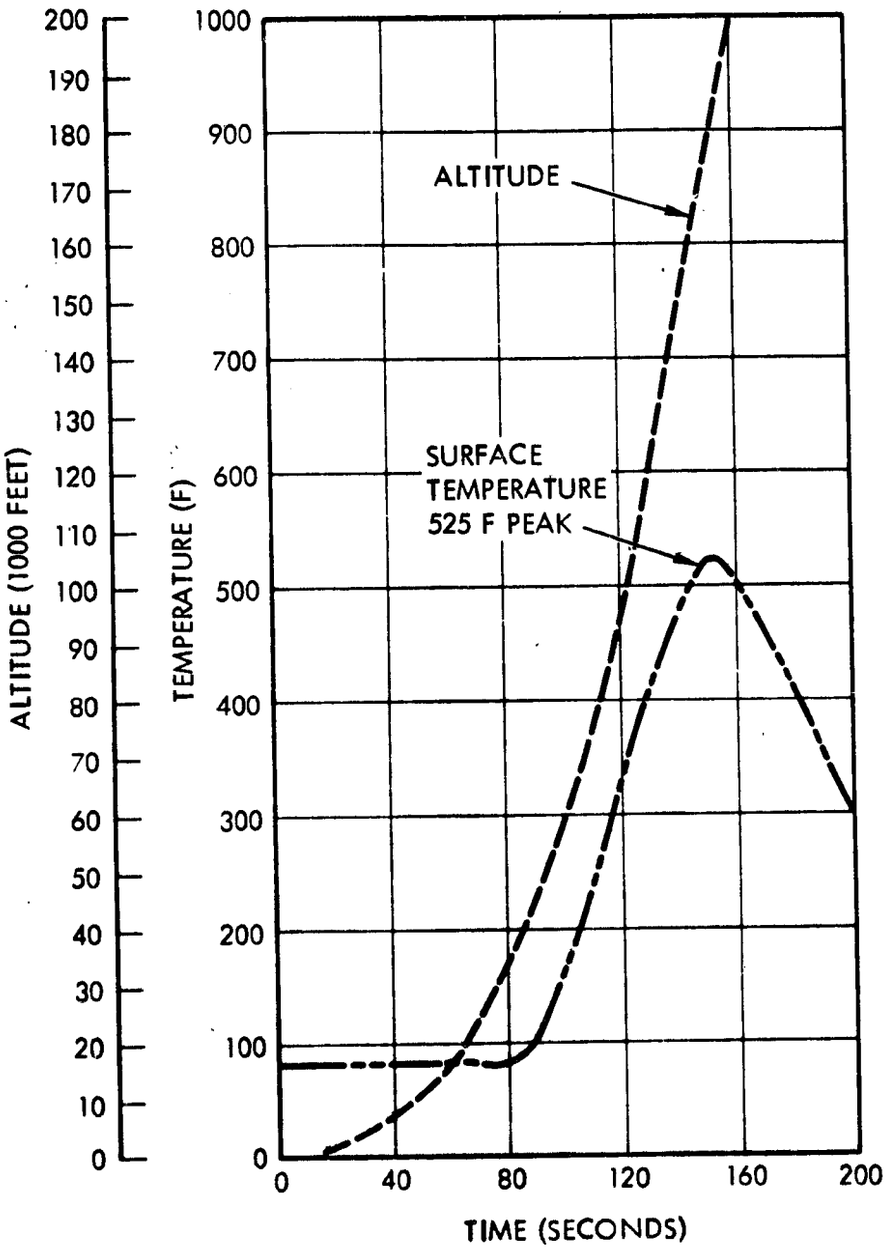


Figure 5.3.1.2-1. Thermal-Altitude Profiles

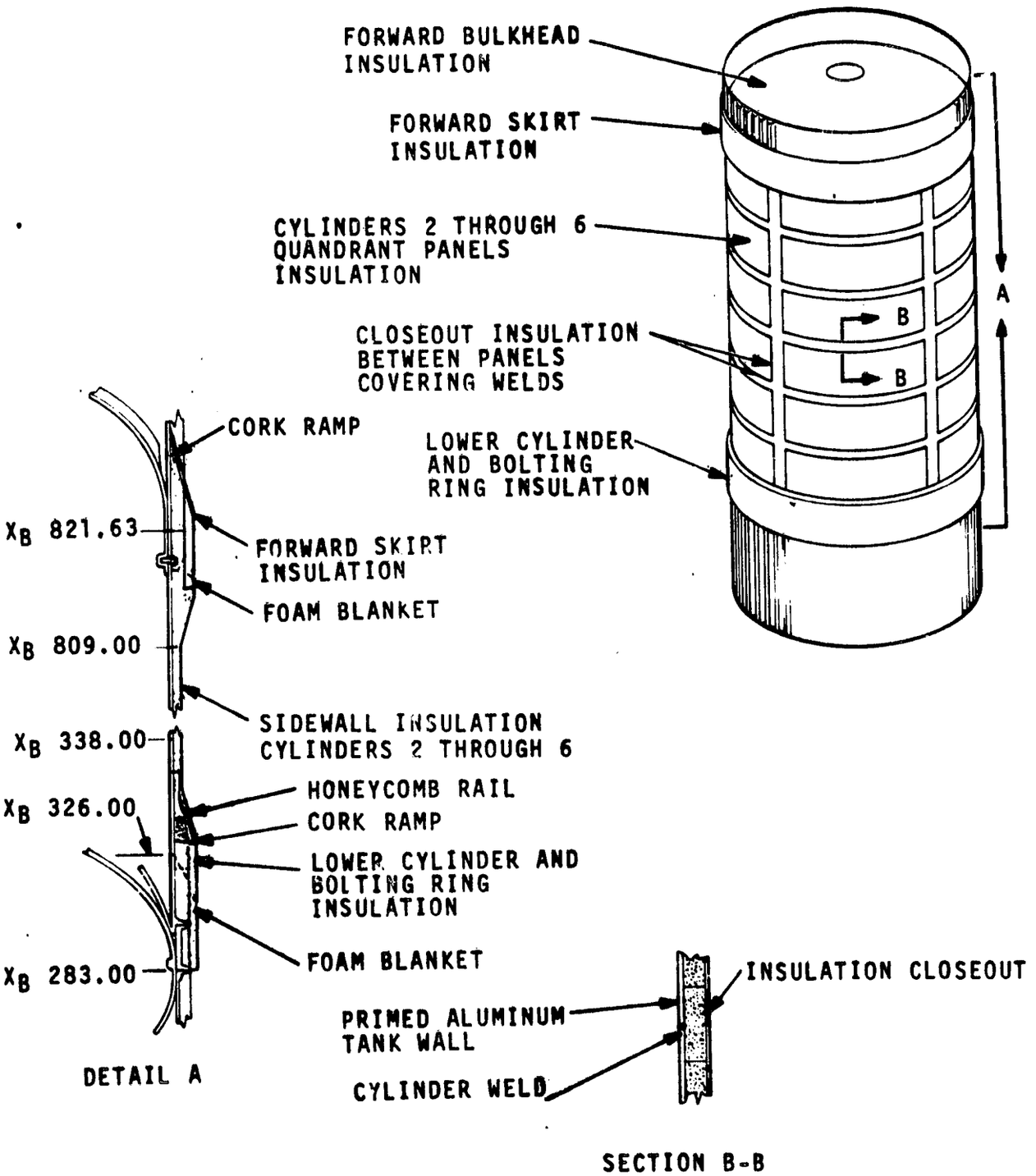


Figure 5.3.1.2-2. Spray Foam Insulation

Table 5.3.1.2-1. Insulation System Performance

Parameter	
Ground Hold LH_2 Boiloff	Allowable - 159 lb LH_2 per minute (6% per hr) Prior Stages - 110 lb LH_2 per minute S-II-8 - 49.5 (MTF - cold day) S-II-9 - 57 (MTF - hot day)
Flight - Total Heat to LH_2 From All Sources	Allowable - 209,000 Btu Prior Stages - 140,000 - 170,000 Btu S-II-8 - 65,000 Btu S-II-9 - 65,000 Btu
LH_2 Temperature at Engine Inlet at T-22 Seconds	Redline - -420.5 F S-II-8 - -422.1 F S-II-9 - -422 F
LH_2 Temperature at Engine Start	Allowable - -416.3 F (43.7 psia) S-II-8 - -422.0 F (T + 164 Sec) S-II-9 - -422.4 F

5.3.1.3 High-Performance Insulation

The need to store cryogenic fluids for extended periods, particularly in space, requires thermal performance greatly in excess of the purged honeycomb base system or the foam system previously discussed. Typical design requirements for a reusable system to store LH_2 for days in a space environment is discussed in this section.

a. Detail Design Requirements:

1. Study Application:

Tank Capacity (LH_2) - 450 ft^3

Tank Surface - 300 ft^2

2. Environment:

Maximum Environment Temperature	- +300 F
Vehicle Compartment Purge	- GN_2 with -60 F dew point
Compartment Temperature	- 21 F minimum to 115 F maximum
Multi-layer Insulation System Purge	- He with -60 F dew point during cryogenic operations and reentry

Preconditioning Purge	- 200 F GN_2 with -60 F dew point if required prior to He purge and cryogenic fill

3. Weight: System weight including LH_2 boiloff to be minimized.

4. Operational: As shown in Table 5.3.1.3-1.

b. Configuration: A system utilizing multi-layer insulation in the natural lay configuration was fabricated for test, as described in Paragraph 6.1.10.

5.3.2 Propellant Transfer Lines

The principal requirement for propellant transfer lines is to enable delivery of proper quantity of propellant to the engine pump inlet at temperatures and pressures within starting and operating limits. Generally, the lines must pass through areas of extreme environments and involve complex geometrical contours, dynamic segments, and structural contours. Propellant flow rate through the lines vary with stage operation. The key requirement for the insulation system is to provide thermal protection to the flowing propellant within the lines. Typical flow rates for the J-2 engine on the S-II stage are 80 pounds per second for LH_2 and 400 pounds per second for LOX.

5.3.2.1 Vacuum Systems

Vacuum-jacketed lines were employed on the S-II stage for both the LH_2 and LOX transfer. Design requirements were developed for the line and evacuated jacket as a single component. MC 271-0011 and MC 271-0010 present comprehensive design requirement listings; however, representative design requirements are presented in this section. Since the vacuum insulation system is not separable from the line, the same requirements apply to the vacuum jackets that apply to the line. The S-II configuration is discussed in Paragraph 6.2.1.

a. LH_2 Feedline and Vacuum Jacket:

Flow	- 80 pounds LH_2 per second
Inlet Pressure	- 88 psig
Pressure Drop	- 1.15 psi for 80 pounds LH_2 per second flow
Heat Loss	- 30.0 Btu/hr/ft^2 maximum with internal wall temperature of + 80 F.
Vacuum Jacket Pressure	- 10 ±5 microns Hg, not to increase more than 150 microns in 30 days (jacket filled with CO_2)

Table 5.3.1.3-1. Requirements - Purged Multi-Layer Insulation System

	PRE-LAUNCH	LAUNCH	ORBIT	RE-ENTRY	STORAGE	RECYCLE
THERMAL PERFORMANCE	NO ICING OR MOISTURE CONDENSATION IN ENVIRONMENT OF GN_2 WITH -60°F DEW POINT	(SEE ORBIT	1. LIMIT LH_2 LOSS TO 1.15% OF INITIAL LOAD IN 7-DAY PERIOD INCL PRELAUNCH & LAUNCH PHASES 2. MAX HEAT RATE = 53 BTU/HR THRU MLI 3. MAX VAPOR PRESSURE = 20 PSIA	NO CRYOGEN	NO CRYOGEN	NO CRYOGEN
STRUCTURAL INTEGRITY	NO DEGRADATION DUE TO REPEATED THERMAL SHOCK	1. NO DEGRADATION DUE TO VENTING OF TRAPPED GAS, ENVIRONMENT OR LAUNCH LOADS 2. PROFILE - FIG 5.3.1.3-1, -2, -3		1. NO DEGRADATION DUE TO HEAT, PRESSURE, OR RE-ENTRY LOADS 2. PROFILE - FIG 5.3.1.3-4 3. MLI OUTER SHIELD TEMP = 300F FOR 15 MIN	AMBIENT TEMP NO LOAD	NO DEGRADATION DUE TO PRE-CONDITIONING PURGE FLOW OR HEAT
PURGE SYSTEM	1. EXCLUDE CHEMICAL & MOISTURE CONTAMINATES 2. EXCLUDE CONDENSABLE GASSES		(SEE LAUNCH)		EXCLUDE CHEMICAL & MOISTURE CONTAMINATES	REMOVE MOISTURE BY FLOWING HEATED GN_2 THROUGH MLI
PRE-CONDITIONING SYSTEM		..T APPLICABLE	NOT APPLICABLE	SEE REPRESSURIZATION SYSTEM		
VENT SYSTEM	PERMIT FLUSH OF PURGE BAG FROM PURGE BAG	1. PERMIT GAS TRAPPED IN MLI TO VENT 2. PRESSURE TO DECREASE TO 10^{-4} TORR IN 1 HR	ERMIT GAS AND VAPOR TO VENT TO ATMOSPHERE TO MINIMIZE MLI PRESSURE	SEE REPRESSURIZATION SYSTEM	PERMIT FLUSH OF PURGE SYSTEM	VENT EFFLUENT PRE-CONDITIONING PURGE GAS
ON-BOARD HELIUM REPRESSURIZATION SYSTEM	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	REPRESSURIZE MLI WITH NON-CONDENSABLE PURGE GAS TO PREVENT STRUCTURAL DAMAGE & AIR LIQUIFACATION	NOT APPLICABLE	NOT APPLICABLE
OPERATIONAL LIFE	NUMBER OF REUSE CYCLES - 100 LIFE SPAN - 10 YEARS					

Space Division
North American Rockwell

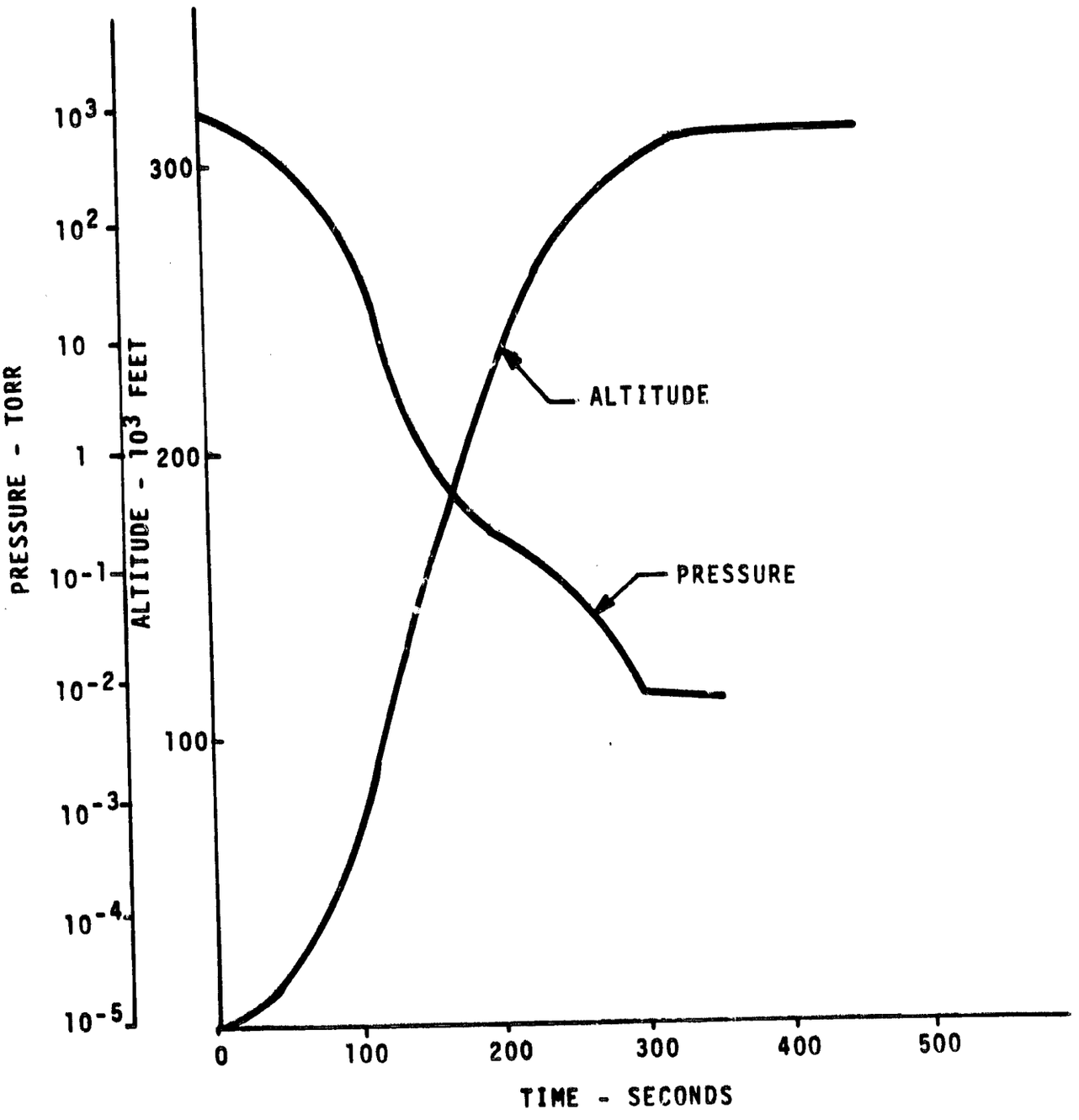
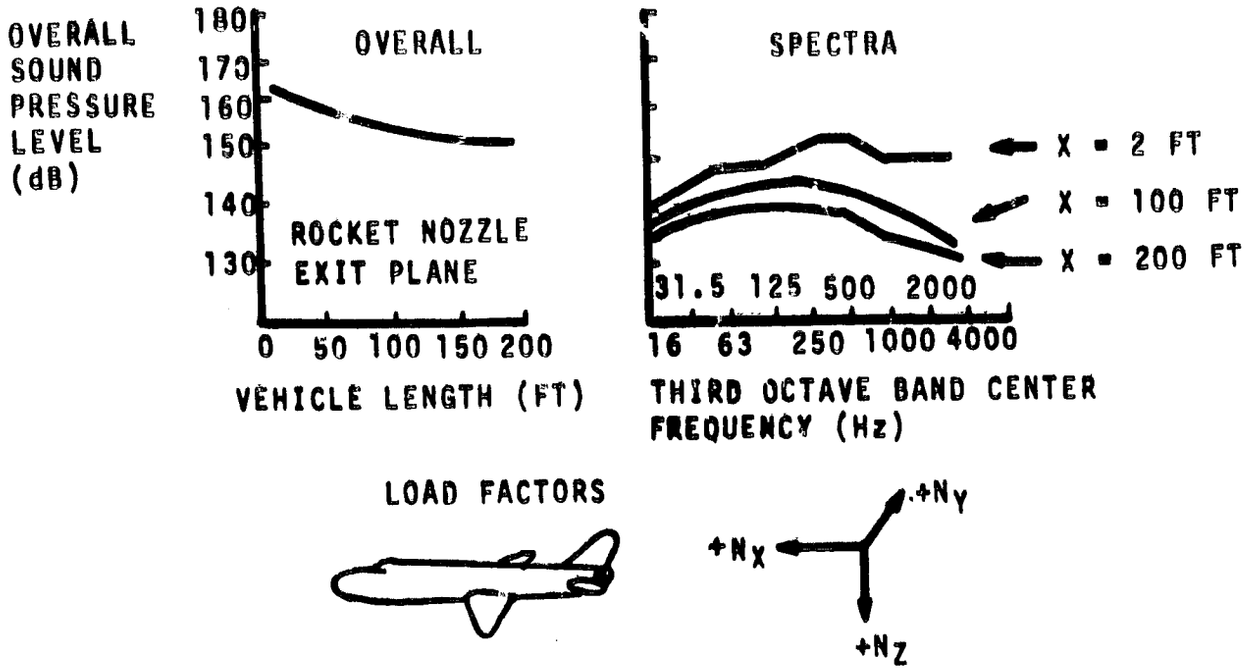


Figure 5.3.1.3-1. Ascent Profile

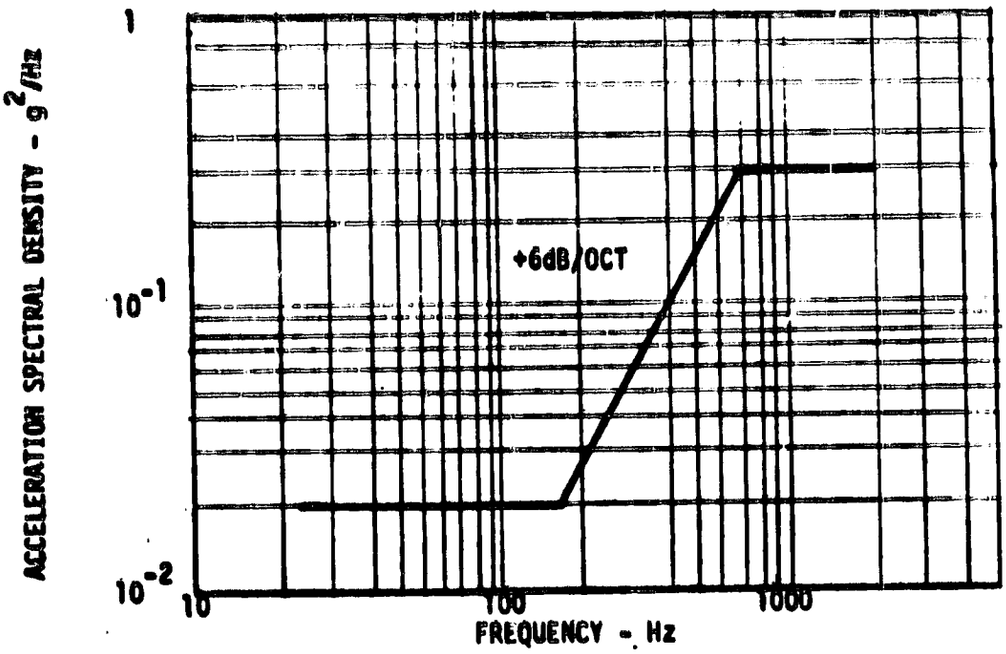
ACOUSTICS ON LAUNCH PAD (12-500K ENGINES)



CONDITION	N_X(g)	$\pm N_Y$(g)	N_Z(g)
LAUNCH	1.5	0.5	-0.5
HIGH Q (BOOSTER THRUST)	1.9	1.0	±1.0
END BOOST	3.3	1.0	-1.0
END BURN (ORBITER BURN)	3.3	0.5	-0.5
ENTRY	-0.5	1.0	-2.0
FLYBACK	-0.5	1.0	+1.0 -2.5
LANDING	-1.3	0.5	-2.7
CRASH	-10	0	-5

Figure 5.3.1.3-2. Imposed Dynamic Environment

VIBRATION CRITERIA



LANDING SHOCK CRITERIA

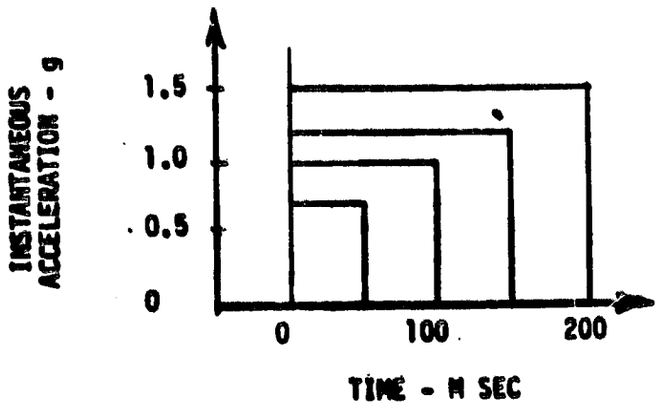


Figure 5.3.1.3-3. Load Criteria

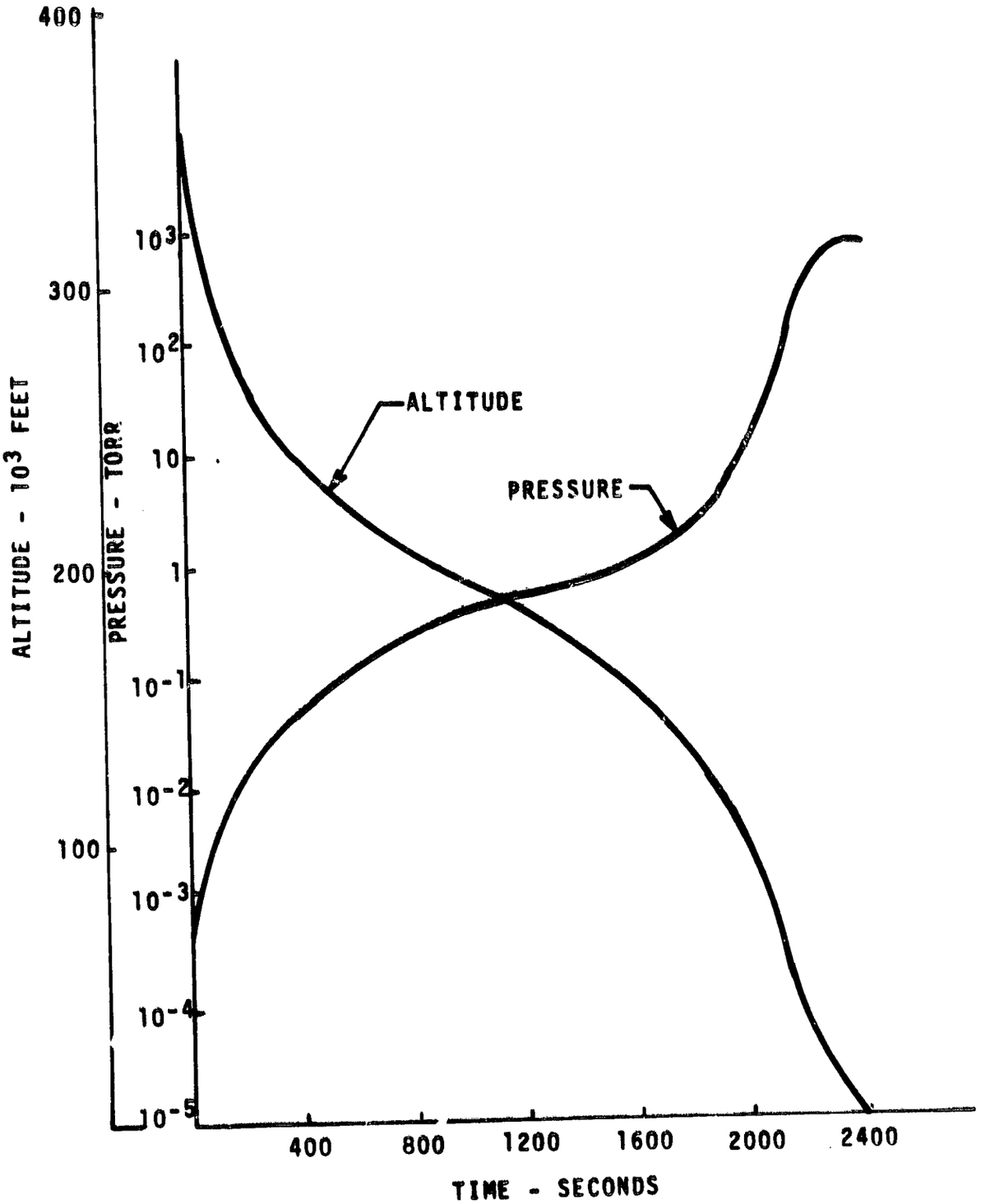


Figure 5.3.1.3-4. Re-Entry Profile

Implosion Pressure - The jacket must withstand negative pressure differential of 22 psi.

Operating Temperature - -180 to + 300 F.

Altitude - Sea level to 820,250 ft.

Structural Movement - The feedline assembly must be capable of deflecting from installed position as follows:

The centerline of the attached flange (Point A) moves 0.30 inch maximum forward and 0.30 inch inboard. Relative to Point A, a second Point B located at centerline of the free end of the feedline moves 0.20 inch maximum toward centerline of the vehicle and 0.500 inch aft.

Thermal Expansion - While fastened to the vehicle structure and without benefit of vehicle expansion, the line assembly must be capable of free movement without binding the flexible bellows joint when the line assembly temperature is increased from 70 to 300 F or decreased from 70 to -425 F.

Operating Life - The line assembly must be capable of successful performance during and after all conditions of test, checkout, prelaunch operation, and flight for a minimum of 1500 cycles. A cycle is defined as the movement described previously.

b. LOX Feedline and Vacuum Jacket:

Flow - 400 pounds LOX per second

Inlet Pressure - 88 psig

Vacuum Jacket Pressure - 10 ±5 microns Hg, not to increase more than 150 microns in 30 days (jacket void filled with CO_2).

Implosion Pressure - The jacket must withstand negative pressure of 22 psi.

Heat Transfer - 45.0 Btu/hr./ft.^{2} of external surface with internal temperature of -320F and external temperature of 80 F.

Operating Temperature	- -180 to + 160 F
Altitude	- Sea level to 820,250 ft.
Thermal Change	- With the line assembly stabilized at room temperature and fluid temperature of minus 300 F introduced at the inlet flange, the line assembly must be capable of stabilizing at 300 F without leakage or permanent distortion.

5.3.2.2 Batting

Design requirements discussed in the preceding section are based on delivery of cryogen of acceptable quality to the engine pump inlet. The complex geometry associated with routing feedlines from the tank interface to the engine interface generally involves elbows, flanges, valves, gimbal points, and structural attachments. Each of these are potential heat shorts.

In cases where vacuum-jacketed systems cannot be utilized in total or in part to meet the basic thermal protection requirements, other insulation systems can be employed. Battings, as described in Paragraphs 6.2.3 and 6.2.4 can be used.

Design requirements related to system performance and environmental conditions remain the same, with the additional requirement that all material be LOX-compatible.

On the S-II stage silica batting encased in thin-gage CRES was used to encase the LOX sump, elbows, and portions of the lines not insulated by vacuum-jacketed system. This design is discussed in Paragraph 6.2.3.

5.3.2.3 Foam

The use of foam insulation to reduce heat leak into the feedlines offers numerous design advantages, particularly in the areas of complex geometry and where closeout must be accomplished after line installation. An example of such application is the feedline elbow insulation on S-II stage.

Design performance requirements remain the same as previously defined; however, there are additional requirements related to the compatibility of the foam insulation and the feedline material.

a. Structural Strains: The interface bond between the foam and the feedline surface must withstand strains imposed by the feedline when pressurized and deflected to maximum limits while at -423 F.

b. Corrosion Protection: The foam and any associated primer system must protect the feedline surface against corrosion from self-induced or catalyzed sources.

c. Flammability: The foam material must be flame-retardant to reduce fire hazard associated with the use of liquid hydrogen and liquid oxygen.

d. Configuration: This design is discussed in Paragraph 6.2.6.

5.3.3 High Temperature Protection

There are specific areas on the S-II stage which require protection from high temperature as experienced during boost. These areas include the thrust cone area (structures, hardware, and electrical components and containers) which is protected by the rigid and flexible heat shield insulation systems and the interstage structure which is protected by bonded cork and spray-on ablative insulation materials. Design requirements for the insulation systems are defined in this section.

5.3.3.1 Rigid Heat Shield

a. Detail Design Requirements:

1. Temperature: Temperature of heat shield surface (hot face) facing plasma heating is as shown in Figure 5.3.3.1-1. Cold face temperature is not to exceed 300 F at the end of 500 seconds of S-II boost.

2. Pressure: Pressure within the heat shield composite must not exceed a maximum of 0.1 psi differential.

3. Vibration: Loading on a panel due to vibration will be limited to the values given in Figures 5.3.3.1-2 and 5.3.3.1-3.

b. Model Configuration: This configuration is shown in Figures 6.3.1.1-1 and 6.3.1.1-2.

c. Performance: Temperatures of the heat shield and structure were well within the design limits on all flight stages as illustrated from typical data taken from instrumentation on AS509 (Figures 5.3.3.1-4, -5, and -6).

5.3.3.2 Flexible Heat Shield

A flexible portion of the heat shield is required to prove a seal between the rigid shield and the engines or other elements that move.

a. Detail Design Requirements: Temperature and pressure requirements are as shown in Figure 5.3.3.2-1.

b. Model Configuration: A model of the flexible heat shield is shown in Figure 6.3.1.1-1. Methods of attachment of the shield are shown in Figure6.3.4.1-2. For S-II-1 through S-II-12, the flexible heat shield (flex curtain) is made up of a composite of S994 glass fabric and high silica batting. The composite is sewn together with glass thread. For S-II-13 a Refrasil fabric replaced the glass fabric. Quartz thread was used in place of glass thread.

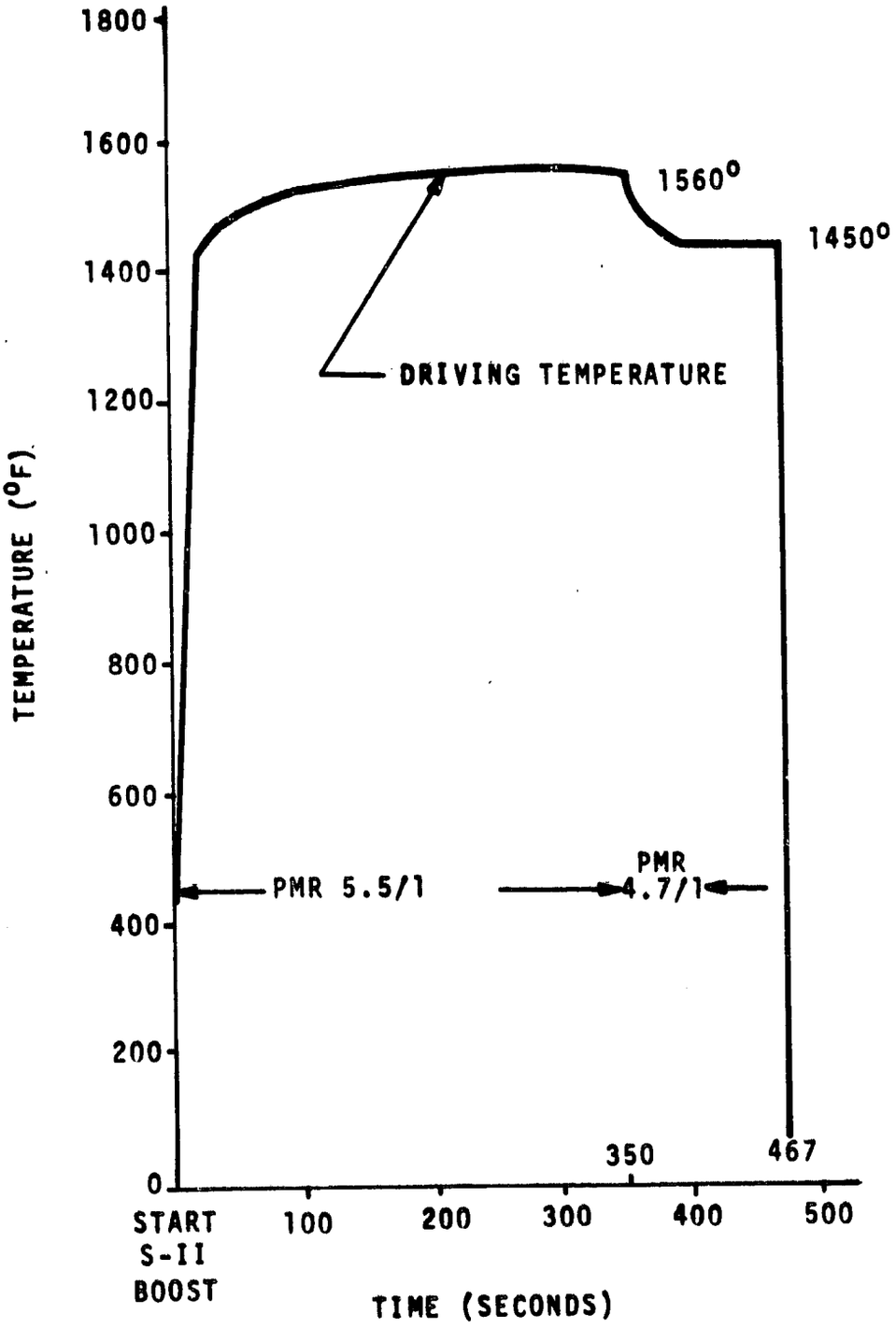


Figure 5.3.3.1-1. Temperature Profile for Rigid Heat Shield - One Engine Out

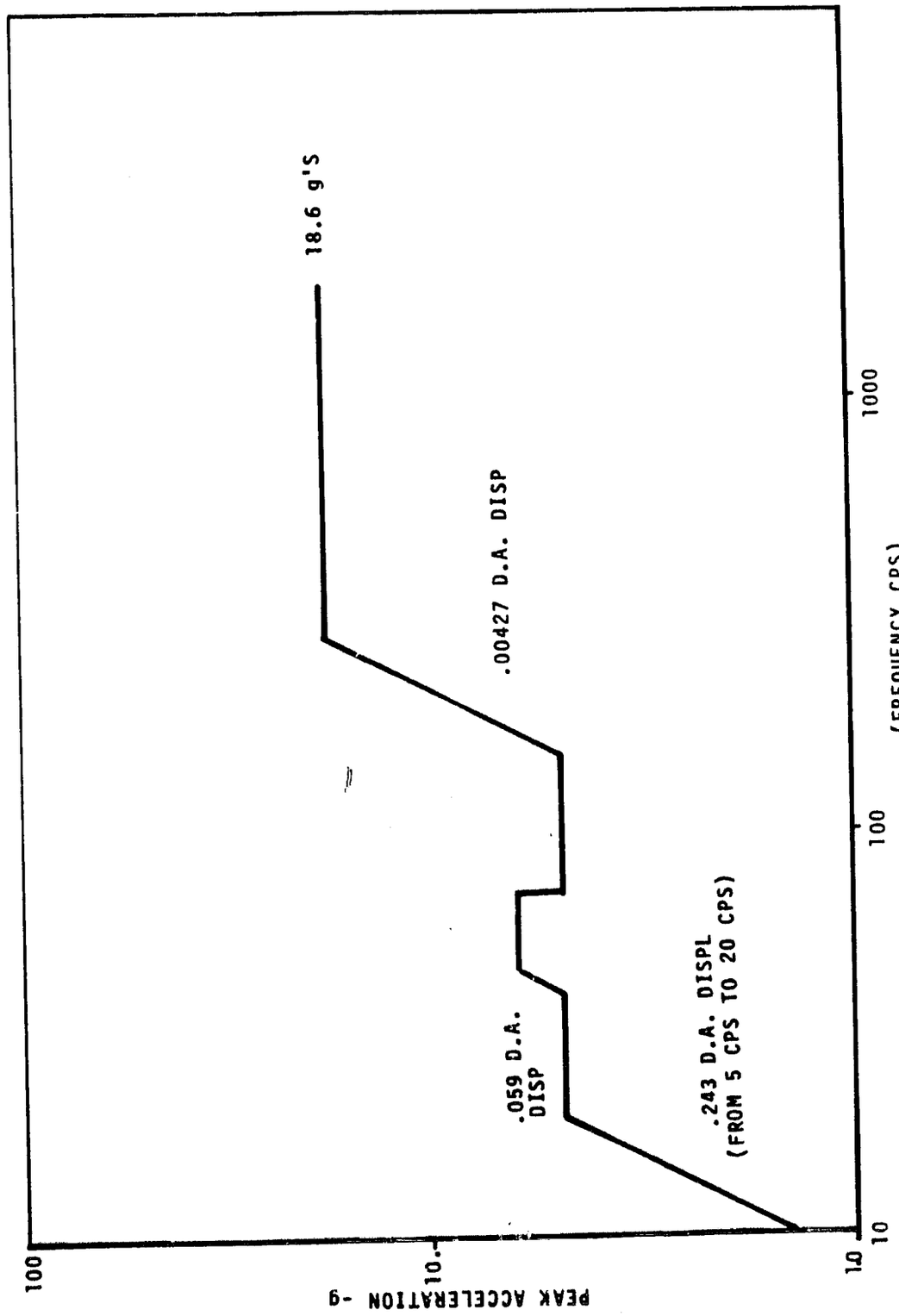


Figure 5.3.3.1-2. Base Heat Shield Input

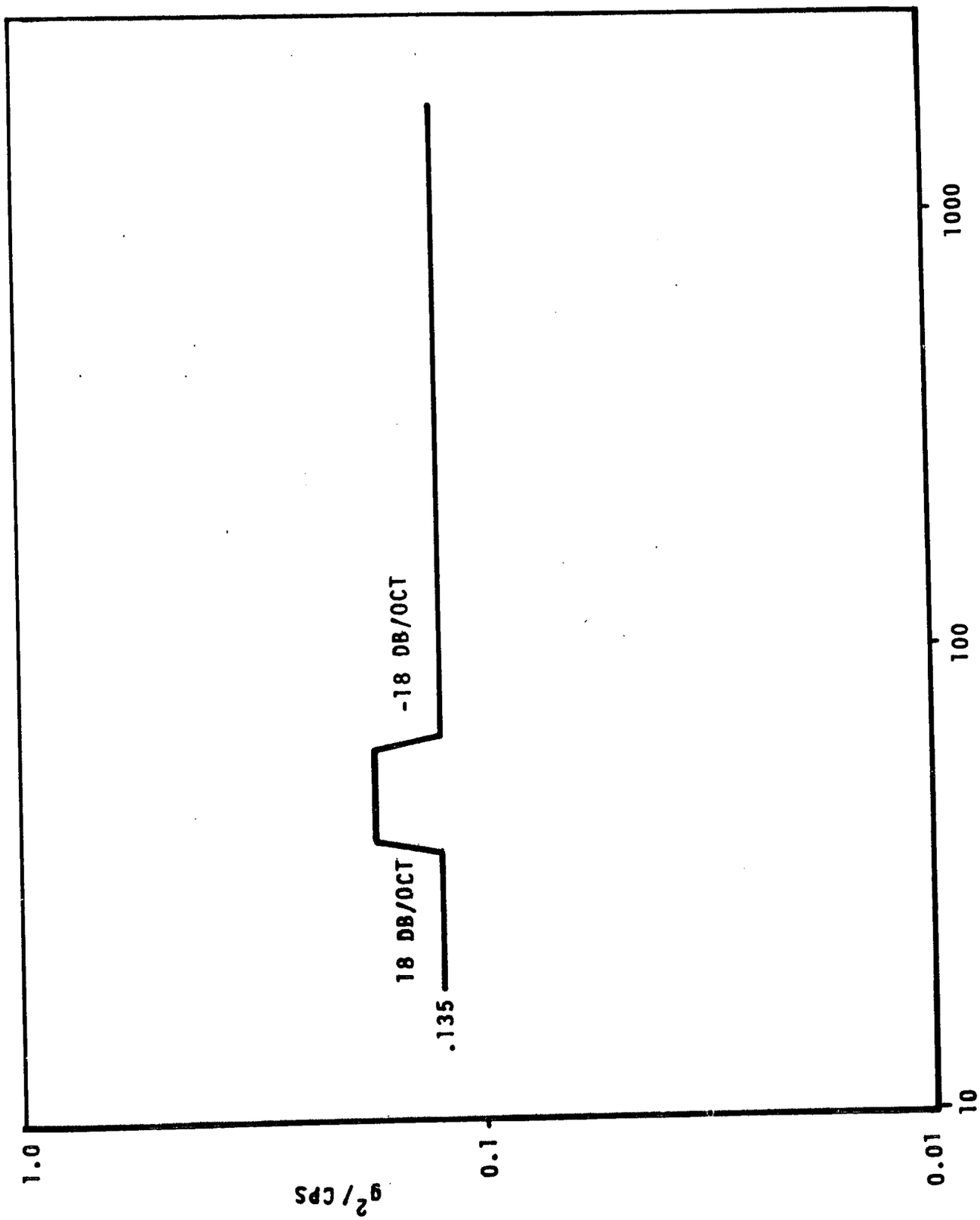


Figure 5.3.3.1-3. Base Heat Shield Random Input

EMR - ENGINE MIXTURE RATIO
OECO - OUTER ENGINE CUTOFF
CECO - CENTER ENGINE CUTOFF

- - - - - - - MAXIMUM DESIGN - NO ENGINE OUT (NEO)

I I MAX PREDICTED FROM PREVIOUS FLIGHTS

——— POSTFLIGHT PREDICTED MAX FOR AS-509

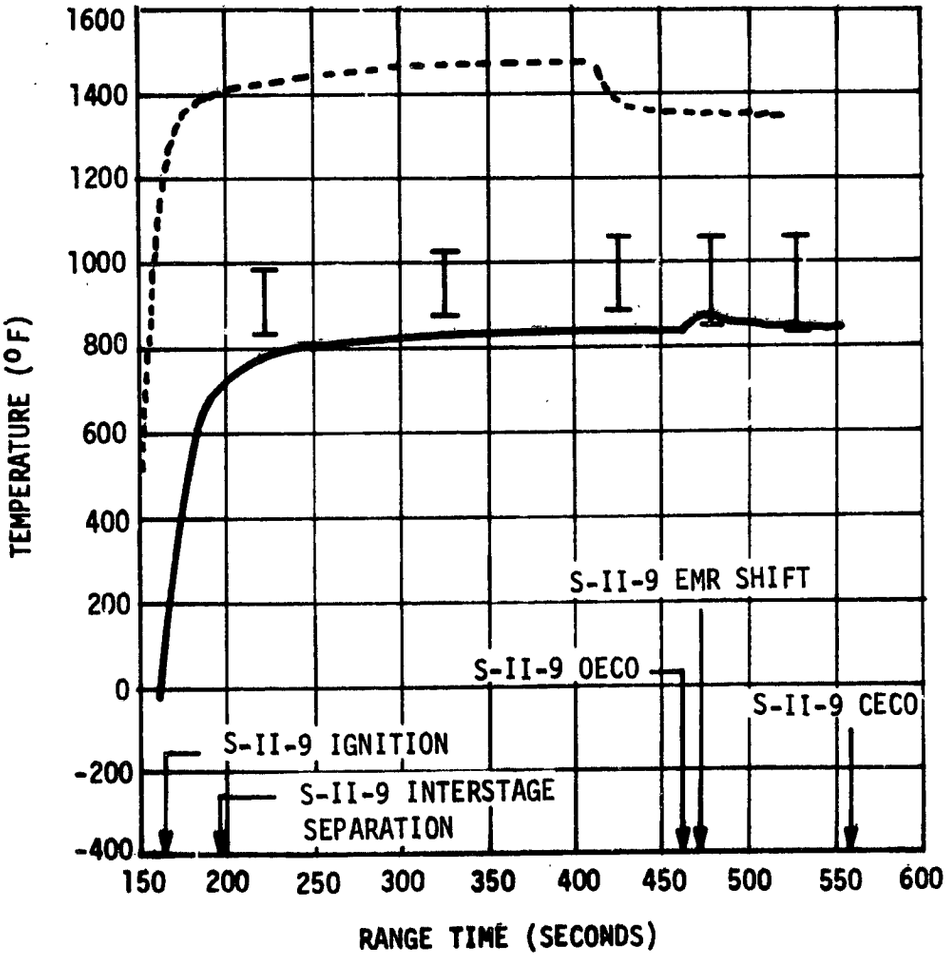


Figure 5.3.3.1-4. Saturn V Flight AS-509 Predicted Maximum Heat Shield Temperature

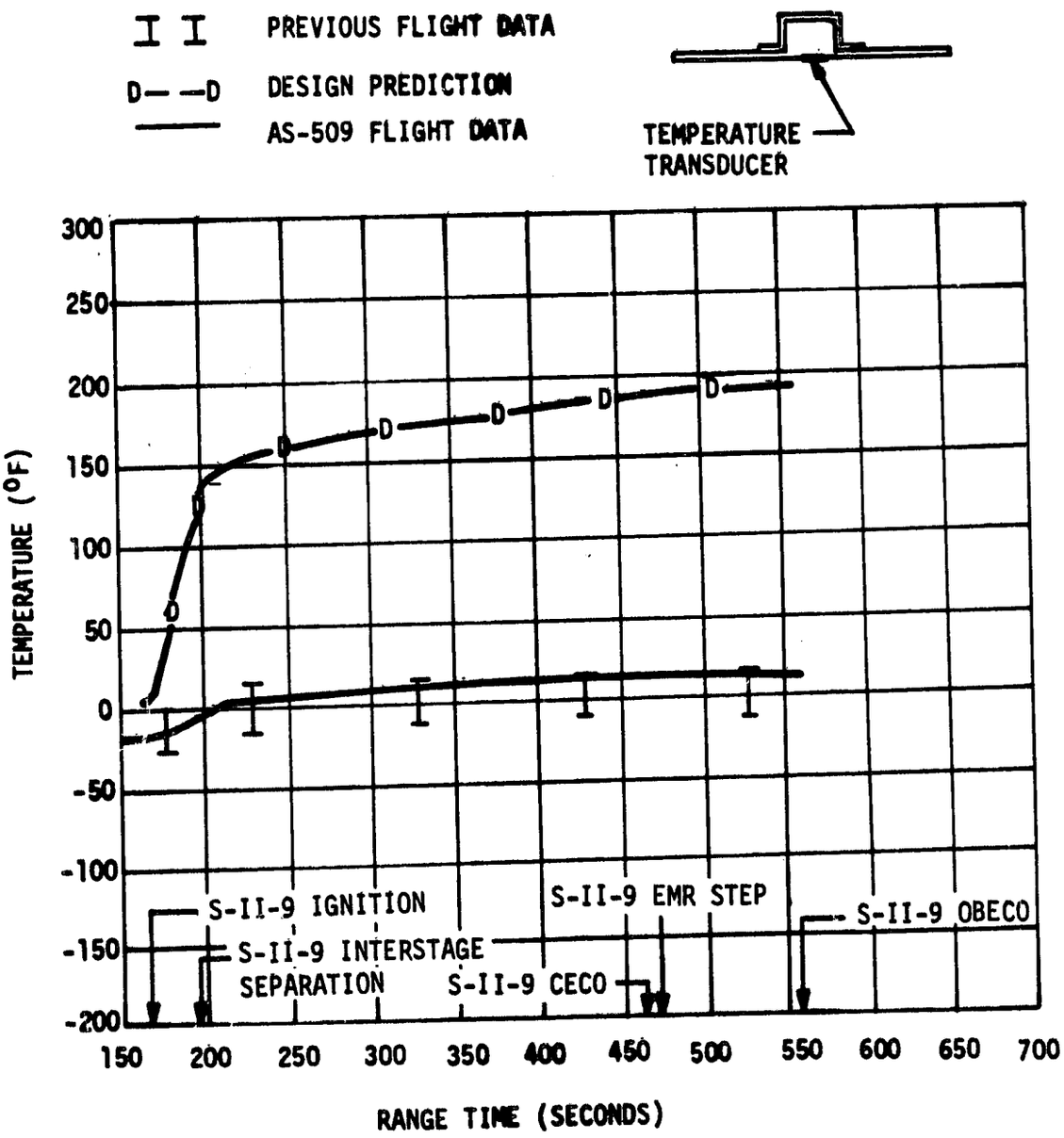


Figure 5.3.3.1-5. Saturn V Flight AS-509, Thrust Cone Forward Surface Temperature

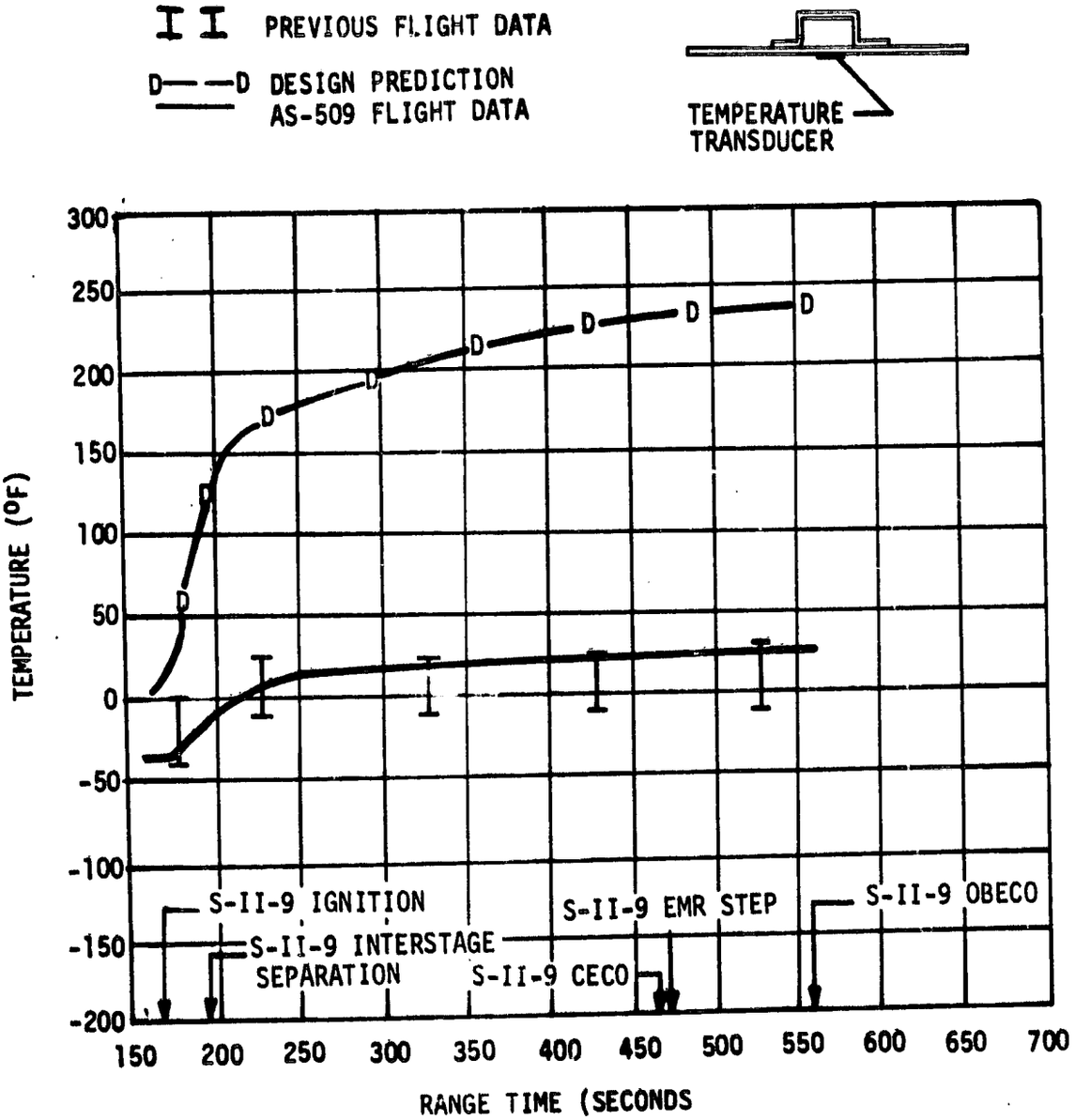


Figure 5.3.3.1-6. Saturn V Flight AS-509, Thrust Cone Forward Surface Temperature

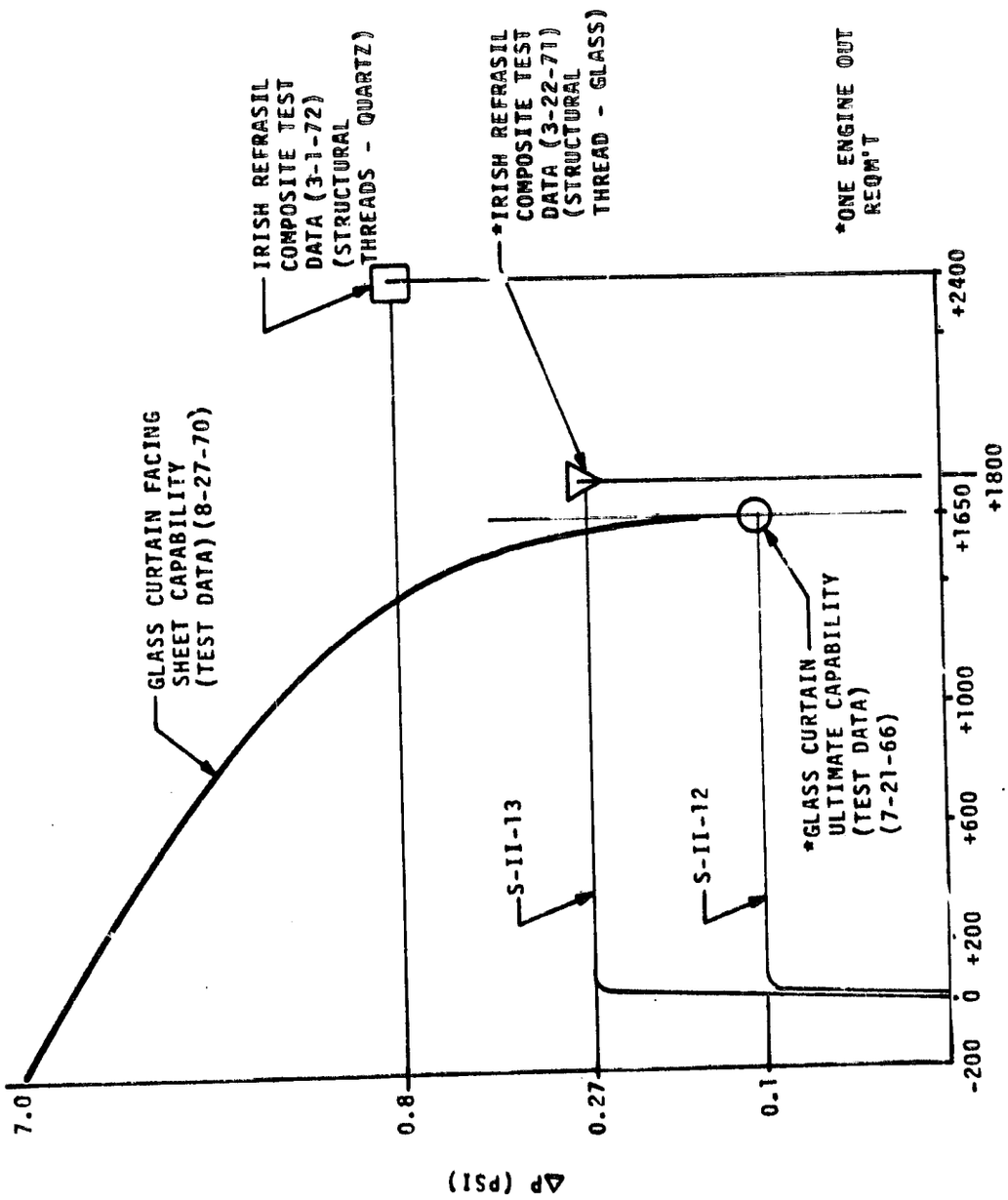


Figure 5.3.3.2-1. Heat Shield Flexible Curtain Tests (Pressure Versus Temperature)

5.3.3.3 Structural Protection

The exterior surface of the aft skirt and interstage structures are exposed to aerodynamic heating during launch.

a. Design Requirements: The systems must be capable of limiting the skirt structure to a maximum temperature of 230 F during S-II boost and to a maximum of 500 F during the first 30 seconds of S-II burn.

This configuration is applicable to S-II-1 through S-II-13 as discussed in Paragraphs 6.3.6 and 6.3.7. It was not required on S-II-14 and S-II-15 because removal of ullage motors and fairings reduced heating and because a heavier skirt structure was used on these last two stages.

b. Performance: Temperatures as measured on AS-501 to AS-503 are shown in Figures 5.3.3.3-1 and -2. The temperature in each case was below that predicted. No temperature sensors were located on subsequent vehicles.

c. Performance: Performance of the flexible heat shield was assessed with the rigid data. Performance data are as described for the rigid heat shield.

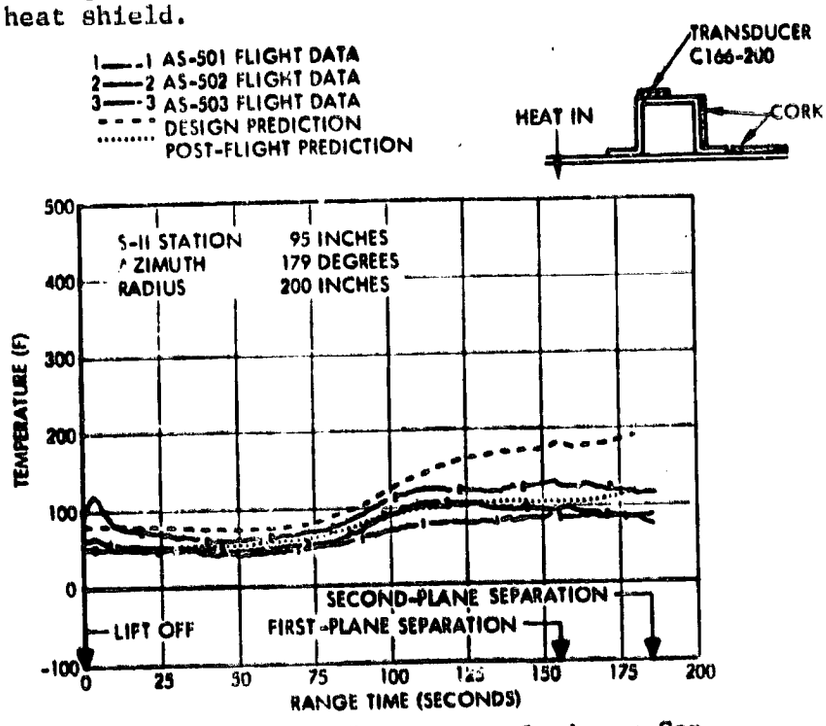
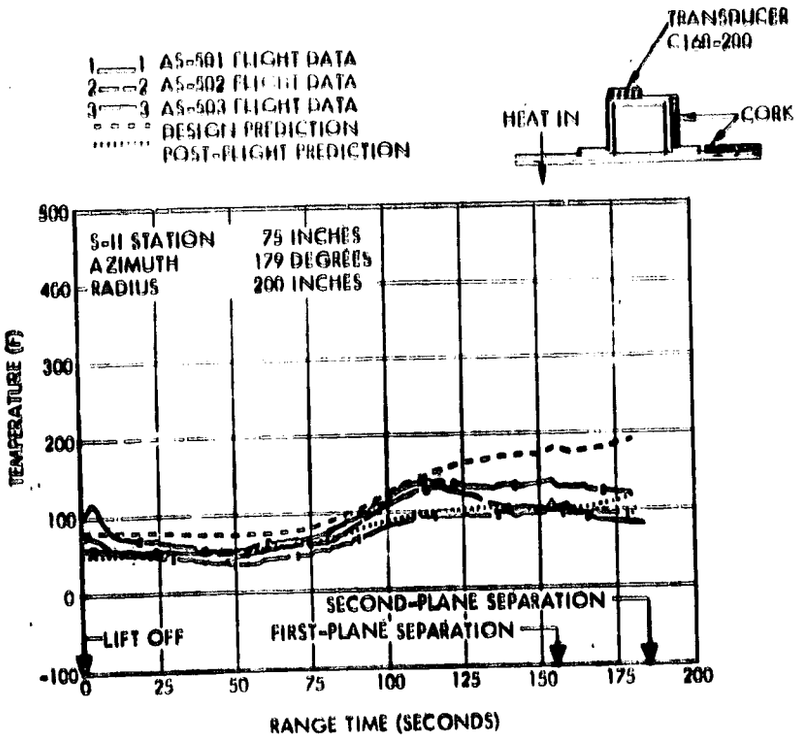


Figure 5.3.3.3-1. Interstage Stringer Cap

5.3.4 Other Insulation Systems

5.3.4.1 Thermal Protection for Avionic Equipment

Insulation is required for thermal protection of subsystem components that are subject to extreme or variable ambient temperature environments while intermittently releasing energy themselves. Prime examples of



Interstage Stringer Cap Temperature (Measurement C168-200)

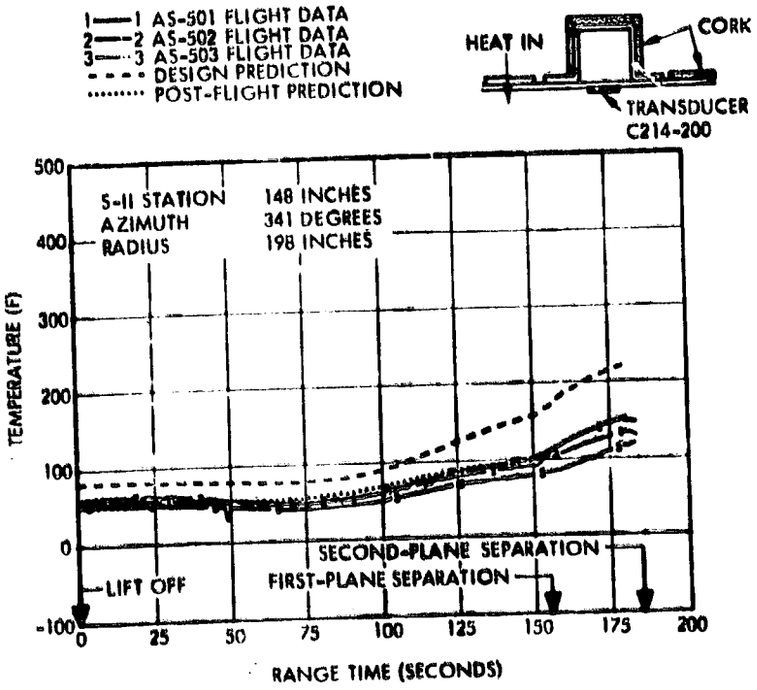


Figure 5.3.3.3-2. Interstage Skin Temperature

this are the equipment containers that house electrical components such as those shown in Figures 6.4.1.1-1 and -2. This section discusses design requirements for insulation of such containers.

The insulation system must provide protection during ground hold, launch, and space operations for the electrical components while they are operating and must provide heating while the components are not operating. Generally the heating is provided by warm purge gas supplied by ground support equipment. The passive insulation system requirements are generally met by proper selection of materials and container design with adequate structural integrity.

Requirements for containers typical of those used for S-II launch stage are presented. Only selected systems are described; however, requirements for all containers can be obtained from SID 62-137. Typical requirements are:

a. Temperature Limits

Protected System	System Temperature (°F)	Heat Dissipation (Watts)
Propellant electronics	0 to +140	115
Radio command	0 to +140	23
Signal condition	0 to +140	156
Telemetry	0 to +140	498
Instrumentation	0 to +140	215
Flight control	-65 to +150	0

b. Purge Pressure Differential - 0.2 psi maximum

c. Electric Consumption - The airborne system will function without solenoid valves and without electric heaters.

d. Purge Gas - To insure compatibility with ground service equipment the system will use air for cooling and nitrogen for heating.

e. Stage/GSE Disconnect Pressure - 1.5 psig for both air and nitrogen.

f. Environment (Typical S-II) - As shown in Table 5.3.4.1-1.

For application to missions involving operation in the space environment for up to 24 hours, such as the INT-21 launch vehicle, additional requirements are imposed. The electrical components must function during orbital operations both before and after cryogens are expended. During orbital operations, design guidelines are materially different

Table 5.3.4.1-1. System Design Conditions

OPERATING MODE (MAXIMUM TIME)	FORWARD AREA (S-II/S-IVB)				AFT AREA (S-II/S-IC)			
	CONTAINER AMBIENT TEMPERATURE (F)		MANIFOLD AMBIENT TEMPERATURE (F)		CONTAINER AMBIENT TEMPERATURE (F)		MANIFOLD AMBIENT TEMPERATURE (F)	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
CHECKOUT (4 HOURS)	20	100	20	100	20	100	20	160
PRELAUNCH (12 HOURS)	-90	0	-50	0	0	40	0	40
ENGINE CHILL (10 MINUTES)	-185	-66	-180	-82	**	40	**	40
S-IC BOOST (155 SECONDS)	-185	-66			-55	40		

S-II BOOST OPERATING MODE (MAXIMUM TIME)		BASE HEATING IN AFT AREA (BTU/FT^2/SEC)			
		MANIFOLD		CONTAINER*	
		CONVECTIVE	RADIATIVE	CONVECTIVE	RADIATIVE
SKIRT ON	5.5/1 PMR (30 SEC)	1.0	0.287	2.8	0.24
SKIRT OFF	5.5/1 PMR (320 SEC)	0.29	0.14	0.16	0.05
	4.7/1 PMR (117 SEC)	0.212	0.106	0.12	0.038

*FOR CONTAINER BASE, CONVECTIVE RATES ARE REDUCED TO 10 PERCENT AND RADIATION IS ZERO

**TEMPERATURE TRANSIENT

TIME = 0 (INITIATION OF CHILLDOWN), TEMPERATURE = 0 F

100 SEC	-20 F
200 SEC	-36 F
300 SEC	-44 F
600 SEC	-55 F

from ground operations. For example, external temperature is a function of vehicle attitude with respect to the sun and the earth and control is required either by orienting the vehicle or by ancillary electric power for heating or by combination.

The design configuration is shown in Figure 6.4.1.1-1 and -3. NR Report SD 70-687 defines requirements for all electrical containers. Design requirements for insulation of typical electrical systems, such as on INT-21, are:

a. Electrical Component Temperature - 0 to 140 F.

b. Purge Pressure Differential - -0.2 psi maximum during ground operations and launch.

c. Purge Gas - To ensure compatibility with ground support equipment the purge system will utilize air for cooling and nitrogen for heating during ground operations. Stage/GSE disconnect pressure must not exceed 1.5 psig for both air and nitrogen.

d. Ground and Boost Temperature Environment - As shown in Table 5.3.4.1-1.

e. Heater Electric Power (typical) - As shown in Table 5.3.4.1-2.

f. Equipment Temperature and Duty Cycle - As shown in Table 5.3.4.1-3.

5.3.4.2 Membrane Seal

Purge gases may be utilized for thermal protection of critical areas where complex structural geometry creates severe fabrication or installation problems, such as the juncture between the forward skirt and forward LH_2 bulkhead on the S-II stage and described in Paragraph 6.4.2 and shown in Figure 5.3.4.2-1. Generally in application of this type the void volume boundaries are structural members but closeouts are required in one or more locations. In Figure 5.3.4.2-1 this is shown as the membrane seal. The principal design concerns for a seal of this type involve retention of purge gas while permitting movement between the structural members. Other systems or program desires may also impose requirements on design.

a. Hazardous Gas: The system must be purged with a non-condensible inert gas during all cryogenic operations.

b. Purge Pressure: Purge pressure across the membrane seal must not exceed 0.1 psi. (On the S-II this pressure represents collapsing pressure on the bulkhead, therefore, constraints are imposed that require the LH_2 tank to be pressurized before the void is pressurized.)

c. Debris Protection: The membrane seal must prevent introduction of debris into the protected area.

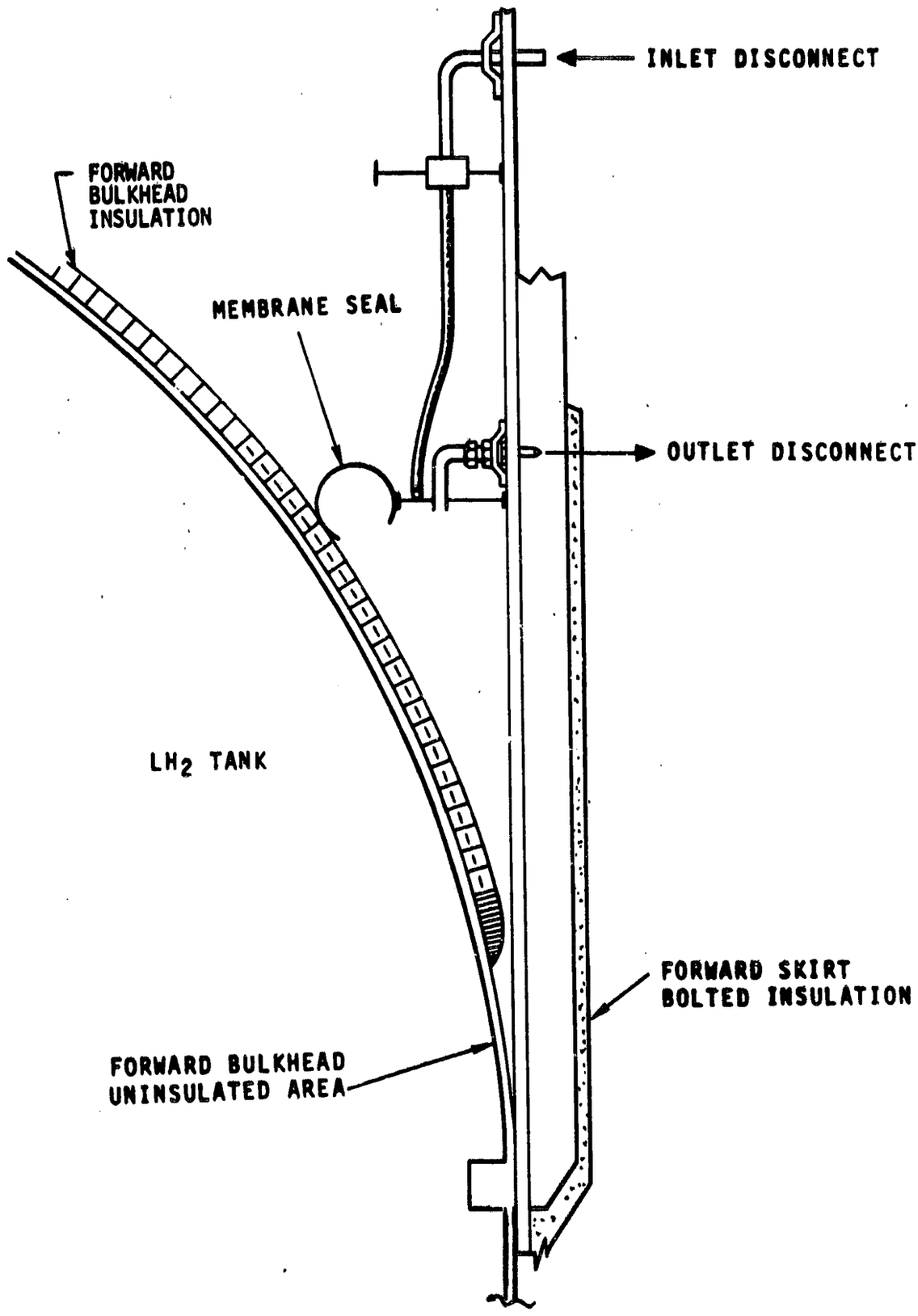


Figure 5.3.4.2-1. Forward Bulkhead Uninsulated Area Cross-Section

Table 5.3.4.1-2. Power Demand for Heaters

Forward Containers	Y-POP*	Z Axis Toward Sun
Forward		
221	None	None
225	None	None
D(225)	None	None
E(225)	None	None
F(225)	None	None
Aft		
206A31	100 watts	None
209	None	None
207	None	150 watts
210	None	None
214	None	None
A(210)	None	None
B(206A31)	150	150
C(206A31)	150	None
Max Total if all heaters go on at same time	400 watts	300 watts
Average (duty cycle)		
206A31	73 watts (73%)	86 watts (58%)
207		
B(206A31)	45 watts (30%)	96 watts (65%)
C(206A31)	120 watts (80%)	
Average total (depending on duty cycle)	238 watts	181 watts

*Y-Axis perpendicular to orbit plane with vehicle nose forward.

d. Water Exclusion: The seal material must prevent passage of water through it but may pass purge gas. Leakage must not occur with water head less than 3 inches.

Table 5.3.4.1-3. Design Requirements and Equipment Temperatures

CONTAINER NO.	DIRECT MOUNTED	ISOLATOR MOUNTED	EQUIPMENT HEAT DISSIPATION IN WATTS	INSULATION THICKNESS IN INCHES	INSULATION ON ALL SURFACES	INSULATION ON BASE ONLY	CRES. ST. FITTINGS WITH FIBERGLAS WASHERS	SURFACE COATING: EXTERNAL — ALUMINUM FOIL α=.2, ε=.1	SURFACE COATING: EXTERNAL — THERMATROL α=.3, ε=.85	SURFACE COATING: COVER — Z-93 α=.3, ε=.91	SURFACE COATING: INTERNAL — AL. SILICONE PAINT α=.25, ε=.28	SURFACE COATING: INTERNAL — THERMATROL α=.3, ε=.95	ATTITUDE & SIDE ** — Y-POP NOSE FWD	ATTITUDE & SIDE ** — -Z AXIS TO SUN	TEMPERATURE — TEMPERATURES WITH CRYOGENIC ENVIRONMENT	TEMPERATURE — TEMPERATURES WITH CRYOGENICS DEPLETED	ELECTRICAL HEATERS — POWER IN WATTS	ELECTRICAL HEATERS — DUTY CYCLE %	ELECTRICAL HEATERS — SWITCH ON +8 F, OFF +33 F
-225		X	360	.125		X			X			X	5		+108 F	•	0		
		X	186	.125		X			X			X	5		+ 76 F	+ 89 F	0		
		X	366	.125		X			X			X		7	+106 F	•	0		
		X	186	.125		X			X			X		7	+ 74 F	+ 80 F	0		
"D"		X	12	.5	X			X			X		1		+ 31 F	•	0		
		X	6	.5	X			X			X		1		+ 26 F	+ 92 F	0		
		X	12	.5	X			X			X			5	+ 15 F	•	0		
		X	6	.5	X			X			X			5	+ 9 F	+ 77 F	0		
"E"		X	11	.5	X			X			X		5		+ 17 F	•	0		
		X	11	.5	X			X			X			7	+ 14 F	•	0		
"F"		X	347	.125		X			X			X	4		+110 F	•	0		
		X	347	.125		X			X			X		6	+103 F	•	0		
221		X	108	.125	X				X			X	4		+ 68 F	•	0		
		X	108	.125	X				X			X		6	+ 57 F	•	0		
-20A31	X		8.5	.5	X		X		X	X		X	8		+ 8 F	+ 97 F	100	73	X
	X		8.5	.5	X		X		X	X		X		2	+ 20 F	+111 F	0		
20*	X		16	.25	X		X		X			X	9		+ 64 F	+119 F	0		
	X		16	.25	X		X		X			X		3	+ 8 F	+109 F	150	58	X
209		X	162	.5	X				X	X		X	5		+ 53 F	•	0		
		X	162	.5	X				X	X		X		7	+ 51 F	•	0		
210		X	226	.125	X				X	X		X	2		+ 20 F	•	0		
		X	226	.125	X				X	X		X		1	+108 F	•	0		
214	X		354	.125	X		X		X	X		X	2		+59 F	•	0		
	X		354	.125	X		X		X	X		X		1	+123 F	•	0		
A		X	172	.5	X				X	X		X	5		+66 F	+96 F	0		
		X	172	.5	X				X	X		X		7	+61 F	+94 F	0		
B	X		0	.5	X		X	X		X		X	4		+8 F	+39 F	150	35	X
	X		0	.5	X		X	X		X		X		6	+8 F	+15 F	150	65	X
C	X		0	.5	X		X	X		X		X	6		+8 F	•	150	80	X
	X		0	.5	X		X	X		X		X		8	+10 F	•	0		

*DENOTES THAT ALL OR PART OF EQUIPMENT IN THIS CONTAINER IS INOPERATIVE AFTER APS BURN FOR SPACE BASE OR S-II BOOST FOR SPACE STATION

6.0 INSULATION DESIGN

6.0 INSULATION DESIGN

6.0 INSULATION DESIGN

The insulation systems defined in this section are divided into the following categories: cryogenic storage, cryogenic transfer, high-temperature protection, and other insulation systems.

An effort has been made to include all significant insulation systems used on the Saturn S-II. In addition, a number of insulation systems defined in technology studies are included. The intent has been to provide basic information that could be used as an aid in selecting the best insulation system to satisfy specific mission requirements. To this end, the following aspects of each insulation design are discussed in brief, with references included to sources of more detailed information:

a. Description

b. Application

c. Thermal performance

d. Structural performance

e. Materials and processes

f. Manufacturing

g. Quality assurance

h. Repair and maintenance

i. Reliability

j. Safety

k. Design effectiveness

6.1 CRYOGENIC STORAGE

6.1.1 Helium-Purged, Foam-Filled Honeycomb Core System

6.1.1.1 Description

The helium purged, foam-filled phenolic honeycomb core insulation system was developed for application on the external surface of the liquid hydrogen tank of the Saturn S-II and was incorporated on S-II-1 through S-II-7. The use of a helium purge to provide an inert atmosphere and to preclude ingestion of condensable gases also allowed the practical fabrication of an insulation composite with less than a perfect external surface seal. The thermal conductivity of this insulation is essentially the same as the thermal conductivity of the helium purge gas.

The design details are shown in Figure 6.1.1.1-1. The basic insulation consists of a foam-filled phenolic honeycomb core composite bonded to the tank

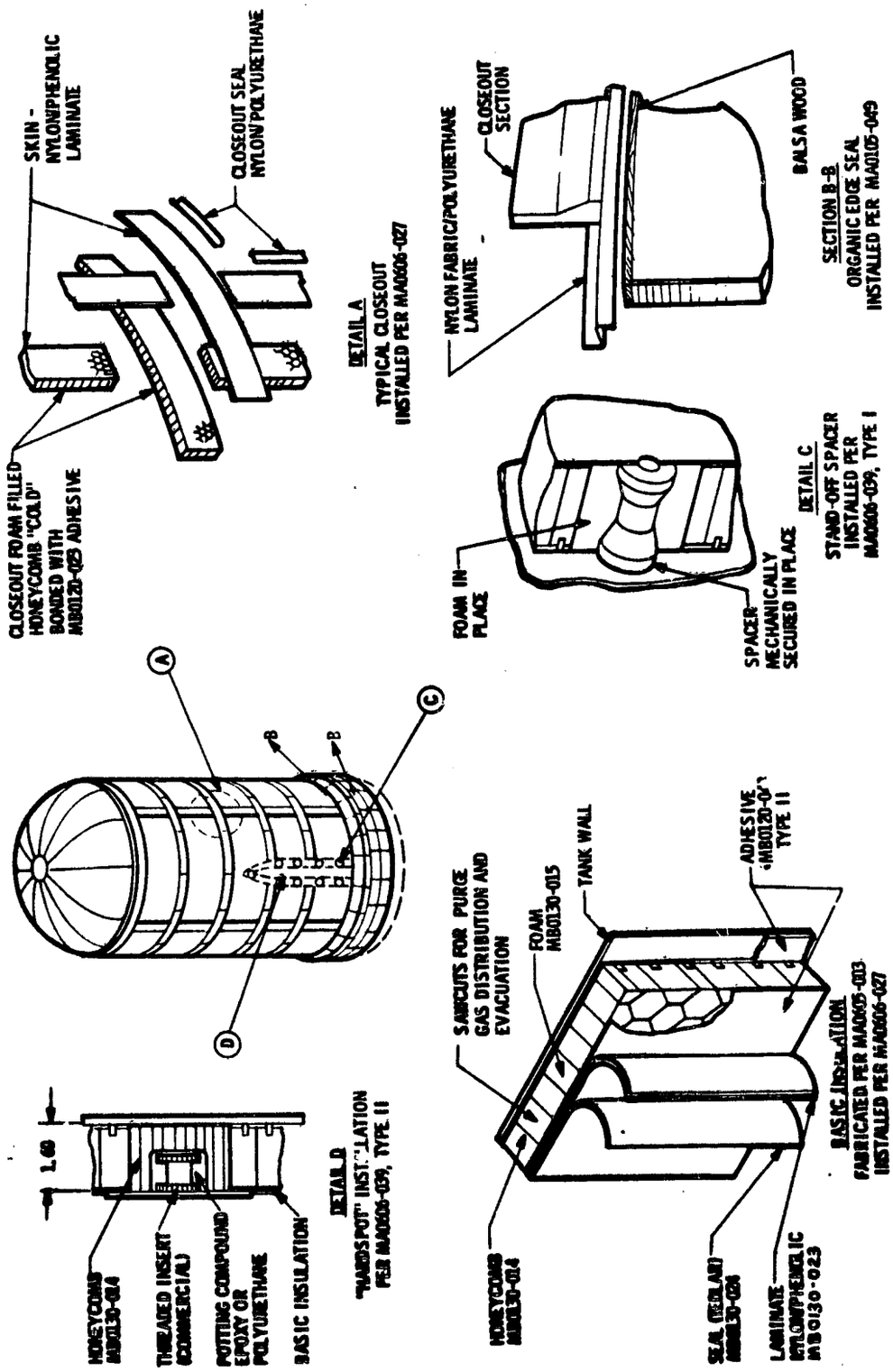


Figure 6.1.1.1-1. Helium-Purged, Foam-Filled Honeycomb System

wall and a non-permeable nylon/Tedlar facing sheet bonded to the external surface of the foam-filled honeycomb core. Saw cuts are provided at the tank side of the foam-filled core to provide a flow path in the insulation panel for the helium gas purge.

Detail A of Figure 6.1.1.1-1 shows a method for closing out between two insulation panels. This closeout was used in the areas of the tank structural welds where access was provided for inspection.

Section B-B of Figure 6.1.1.1-1 shows a method for sealing the edge of an insulation panel. This edge seal, which consists of a balsa wood backup strip and a nylon/polyurethane laminate, also was used as a seal to isolate insulation purge areas.

Detail D of Figure 6.1.1.1-1 shows a potted-in threaded insert (hardspot) used to provide an external attachment facility on the tank. Hardspots were used for supporting such items as wire harnesses, plumbing lines, and small aerodynamic fairings. When the applied loads exceed the structural capability of the hardspot, a standoff spacer was utilized to obtain a tie into the tank structure. Detail C depicts a standoff spacer design.

6.1.1.2 Application

a. Utilization: The principal advantage of the helium-purged honeycomb/foam external insulation system is its ability to provide acceptable thermal protection while simultaneously monitoring leakage of the enclosed primary structure. It is applicable to launch vehicles with operation and constraints similar to the S-II stage.

   The system is also usable for ground storage tanks containing hazardous cryogens where the purge gas will provide indication of leaks and permit dilution to a safe limit. Similarly, since the purpose of the purge gas within the insulation is to preclude intrusion of ambient air, the system can be utilized on applications which require long storage in non-benign or hazardous ambient environment.

   Thermal performance of the system closely approximates that of the purge gas. Nominally, this is satisfactory for applications in ground operations and for short periods during launch but it is normally not acceptable for space operation.

b. Performance Characteristics: This insulation system was utilized successfully on seven S-II flight stages. LH_2 boiloff during ground test was measured at 110 pounds per minute (68 F ambient temperature). This represented an improvement over design allowable of 151 pounds per minute (6 percent per hour). Performance in flight was also better than required, with total heat leak into the LH_2 calculated in the range of 140,000 to 170,000 Btu for the seven flights.

c. System Limitations: This system was developed to meet the requirements of the S-II stage program as discussed in Section 5.0. The materials and

configurations are limited to maximum temperature of +365 F and pressure differential of 6.8 psi on the outer facing sheet of the insulation during flight.

d. Design Problems: The design of an insulation system of this configuration is reasonably simple; however, manufacture can be complex. Design, therefore, must consider the enhancement of producibility. Selection of materials and tradeoff of detail configurations must consider the effects of succeeding manufacturing operations including bonding temperature, pressure, time, and geometry.

Principal design problems experienced during development of the S-II insulation system are summarized in Table 6.1.1.2-1.

Table 6.1.1.2-1. Insulation Problems and Solutions

Problem	Solution
Debond between outer facing sheet and honeycomb core during manufacturing test and on stage	1. Double tape adhesive in thickness to provide better filleting around edge of honeycomb core 2. Increase pressures to preclude bridging of non-uniform areas in honeycomb
Selection of outer laminate thermal compatibility	Select outer laminate with properties to match deflections imposed by primary structure; the dimples which result from the applied vacuum during fabrication are helpful in relieving thermal stresses
Effective closeout bond (local multi-contour surfaces and bonding to Tedlar)	Initial design over closeout area was effective seal but difficult to install; design changed to silicone adhesive which was easy to install but failed when subjected to cryogenic temperature because of gaps in the honeycomb/foam substrate; final solution was to use wet layup design (Detail A of Figure 6.1.1.1-1)
Inspectability (complex contours and hidden bond lines); Handling of Tedlar (wrinkles and pinholes)	Prepare designs to exclude areas where bond lines were not inspectable after cure; utilize special handling procedures and protective devices

Problem	Solution
Debond and voids in bond line (improper surface cleaning, loss of bonding pressure, adhesive overage, adhesive thickness not controlled)	1. Use good in-process control during manufacturing 2. Train personnel properly in organic processing 3. Where complex contours required non-inspectable bonding, provide backup support or minimize local loading; establish in process test following completion of bond
Damage to exterior surface (mechanical, access through insulation, thermal)	1. Provide backup protection in purge system 2. Provide means for identifying location and extent of damage 3. Provide repair procedures
Identification of open cells in foam (volume of purge gas, overpressure in flight, influence in leak detection)	1. Conduct test program to define volume of contained gas in foam lots used
Material selection (thermal strain compatibility)	1. Determine material properties in laboratory for design by analytical techniques 2. Employ analytical design technique using authoritative material properties data for temperature range anticipated 3. Conduct test program to verify integrity of analytical design
Debond from tank wall (thermal stress, primer system)	1. Select adhesive to match thermal contraction of tank well 2. Insure thickness of bond line is below maximum allowable 3. Insure continuity of adhesive interfaces 4. Insure compatibility with primer/adhesive system

c. Design Verification Tests: Tests conducted to verify adequacy of the design simulated conditions by simultaneously applying differential pressure, aerodynamic temperature, and vibration profiles to the specimen which was held at LH_2 temperature. Results were successful in three consecutive tests (SID 66-361).

Figure 6.1.1.2-1 shows the results of one of these tests. Anticipated pressure and temperature profiles are shown as dashed lines and the conditions experienced by the specimen are shown as solid lines (Reference 20).

Subsequent tests also were successfully conducted to demonstrate adequacy of closeout designs and the adhesive used to bond the outer facing sheet to the honeycomb core. A surface temperature of 530 F was experienced without failure during profile heating (Reference 21).

Extreme temperature tests also were conducted. Specimens were subjected to surface temperatures of 700 F at simulated altitudes of sea level, 50,000 feet, 100,000 feet, and 175,000 feet. Charring was experienced in the outer laminate but ignition was not experienced (Reference 22).

Based on these tests, the system was considered satisfactory for flight. Qualification was demonstrated by successful performance in operation. A total of 64 cryogenic operations were experienced by the system on two test stages and seven flight stages.

6.1.1.3 Thermal Performance

The thermal performance characteristics of this design are given for a tank containing LH_2 which is subjected to both ground-hold and launch environments. The hot day ground-hold environment used is defined in Paragraph 4.1.1.2. The launch environment used is the heating rate developed from the maximum aerodynamic heating trajectory for the LOR mission shown. The thermal characteristics presented apply to large areas of basic tank sidewall insulation.

The effective insulation system thermal conductivity as a function of temperature is presented in Figure 6.1.1.3-1. The mean value used for thermal performance characteristics is presented in Figure 6.1.1.3-2. The maximum external surface temperature of 364 F occurs near S-II ignition. The maximum heat rate to LH_2 of 0.1 Btu/ft^2-sec. occurs 160 seconds after the maximum surface temperature. The thermal delay is due primarily to the heat capacity of the insulation system. The predicted total accumulated heat to LH_2 is approximately 40 Btu/ft^2 for the assumed mission profile.

Cold day minimum surface temperatures, maximum temperature gradients and structure temperatures during tank preconditioning, propellant filling and detanking, and protuberance heating effects in localized areas are important thermal performance characteristics related to insulation design. A detailed discussion of the thermal performance and predicted temperature is presented in Section 7.3.1.

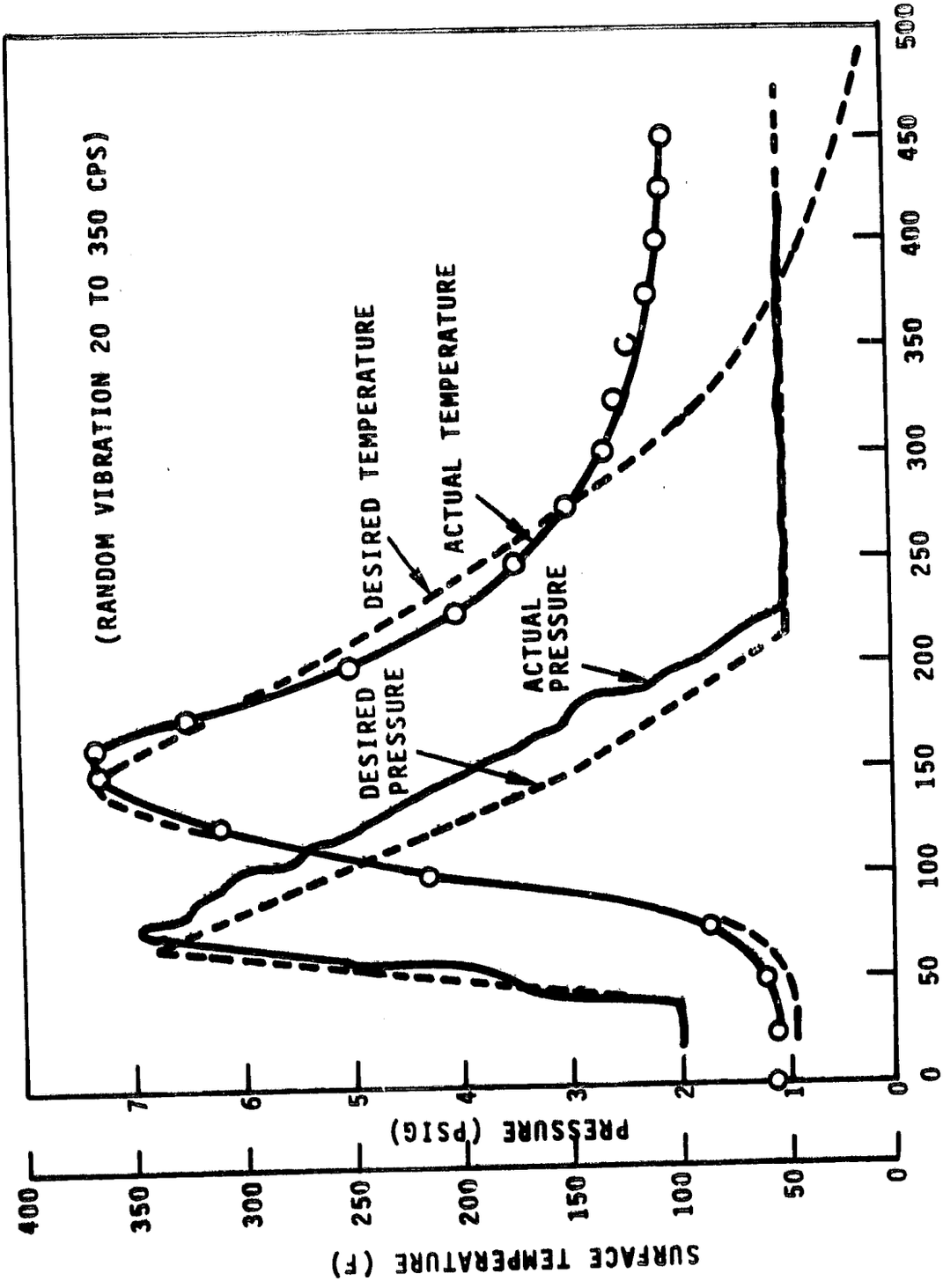


Figure 6.1.1.2-1. Temperature and Pressure Profiles

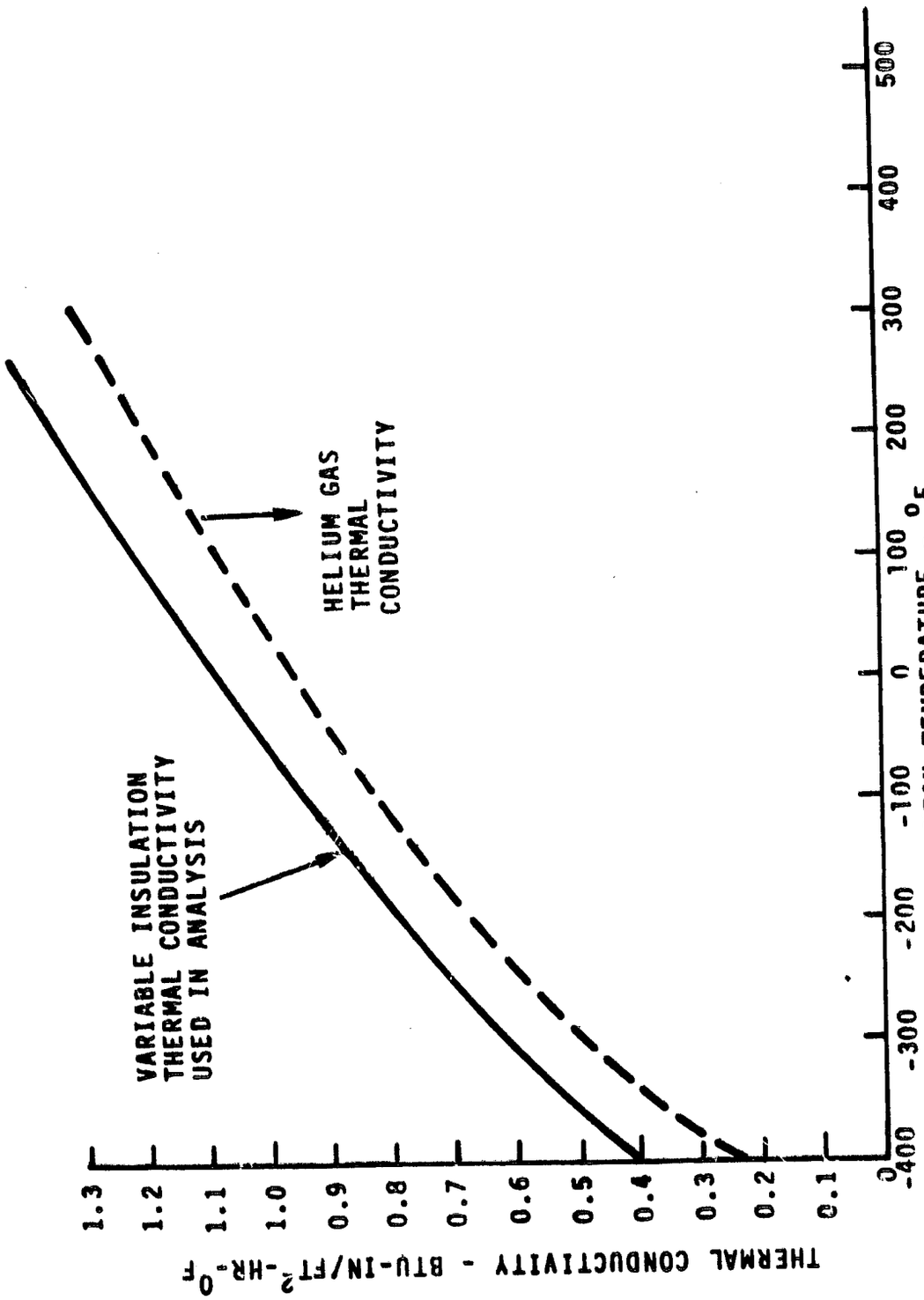


Figure 6.1.1.3-1. Insulation Thermal Conductivity

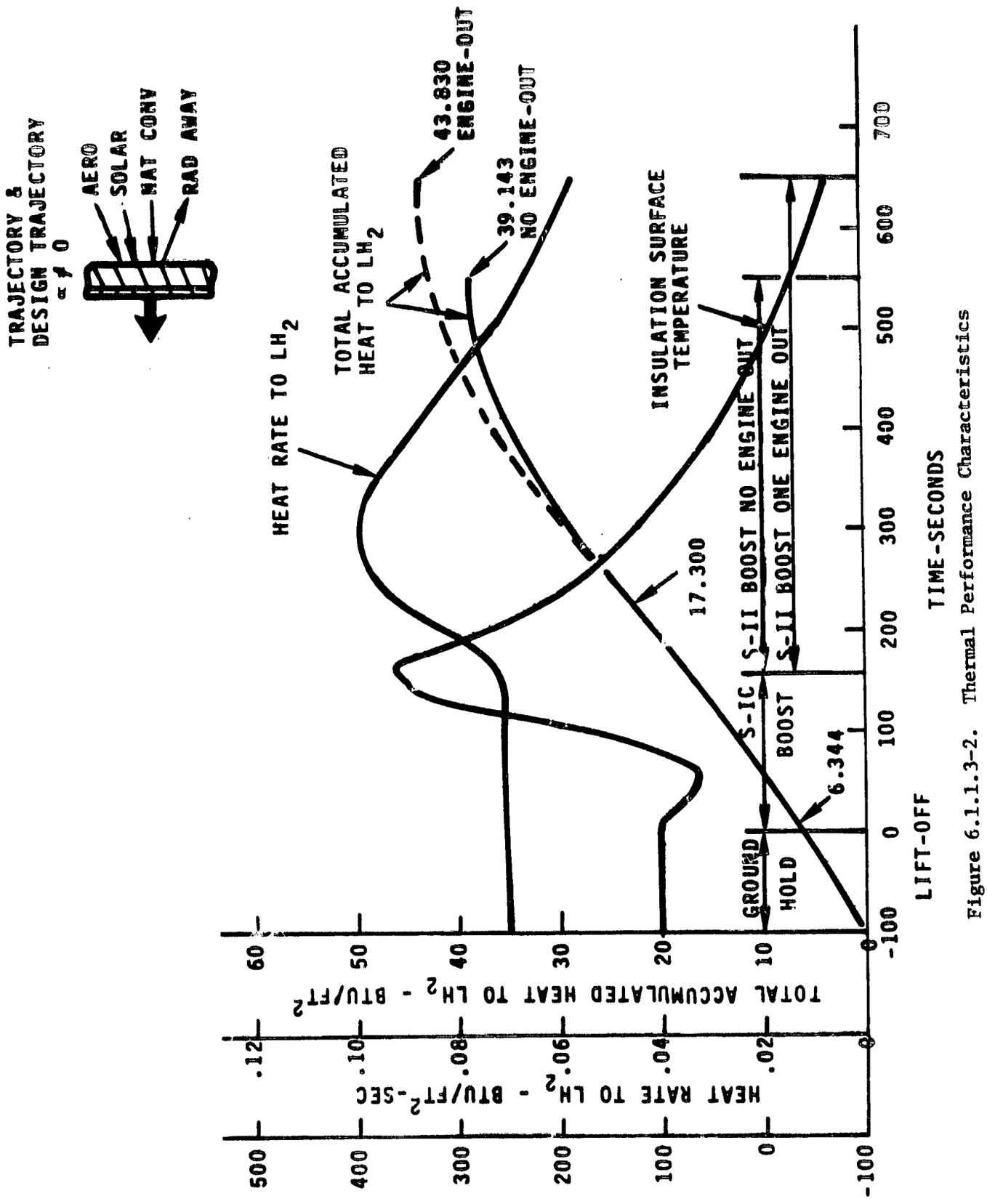


Figure 6.1.1.3-2. Thermal Performance Characteristics

6.1.1.4 Structural Performance

Since the primary function of this insulation system is to provide thermal protection, it is not intended to be a primary load-carrying structure. However, stresses are introduced into the insulation system as a result of thermal gradients through the insulation thickness, differences in thermal contraction and expansion rates between the different materials, LH_2 tank internal pressures, and internal pressure within the honeycomb core.

This insulation system must have strain compatibility with the LH_2 tank. During fill of the LH_2 tank, the tank contracts diametrically. The honeycomb insulation system is required to match the strains and deflections of the tank resulting in stresses in the honeycomb core, nylon facing sheets, and adhesive layers. These stress levels are increased as the tank is pressurized. Helium purge gas also is circulated throughout the honeycomb core which results in a positive pressure within the honeycomb core during tanking and testing. A positive pressure also is exhibited during venting in the launch ascent phase.

Since the honeycomb insulation is of lightweight construction and is continuously bonded to the tank skin, the dynamic properties and response of the insulation is the same as the tank skin. Hence, stresses resulting from dynamic effects are negligible for this type of insulation system.

Of prime importance from a structural analysis standpoint for this type of insulation system are:

a. This insulation system utilizes organic materials which exhibit a visco-elastic behaviour different from normal elastic behaviour of metals. The structural analysis of organic materials is discussed in Section 8.0.

b. The thickness of adhesive layers must be sufficient to insure proper bonding between the core and nylon face sheet in order to sustain the core internal pressure loading. Local debonds propagate rapidly when subjected to differential pressure loading.

c. The effective modulus of the honeycomb composite was reduced by the dimpling which resulted from the vacuum applied during fabrication. This reduction in the effective modulus results in a reduction of the stress levels in the insulation system.

6.1.1.5 Material and Processess

a. Materials:

1. Honeycomb: The core is a non-vented 3/4-inch cell fabricated of glass fabric, impregnated with a heat-resistant phenolic resin (MB0130-014).

2. Foams:

(a) A low density (2.0 lb/ft^3), rigid, polyurethane open-cell foam (MB0130-015).

(b) A low-density (3.0 lb/ft^3), polyurethane pour foam (MB0130-069).

3. Film: A polyvinyl fluoride material (MB0130-024).

4. Fabric:

   (a) Woven nylon cloth impregnated with phenolic resin (MB0130-023).

   (b) Scrim-type glass cloth (MB0135-008).

   (c) Woven nylon cloth (MB0135-021).

5. Primers:

   (a) Two-part phenolic epoxy resin base adhesive primer system (MB0120-032).

   (b) Solvent-carrying phenolic-epoxy primer (MB0120-047).

   (c) A modified polyester/isocynanate adhesive primer system (MB0120-042).

   (d) A zinc chromate, titanium dioxide pigmented epoxy amine primer (MB0125-047).

6. Adhesives:

   (a) A foaming tape adhesive system (MB0120-014).

   (b) A modified epoxy adhesive paste and primer system (MB0120-023).

   (c) A polyurethane resin system (MB0120-024).

   (d) A thixotropic paste adhesive system (MB0120-026).

   (e) A foaming paste adhesive system (MB0120-030).

   (f) Epoxy-phenolic glass fabric supported tape adhesive (MB0120-048).

   (g) Epoxy adhesive system (MB0120-008).

b. Processes: Materials used for fabrication and installation of the basic insulation honeycomb panels were stored, handled, and processed in accordance with Section 11.0.

1. Fabrication of Basic Insulation Honeycomb Panel (MA0605-003):

   (a) Fabrication of Face Sheet: The facing sheet consists of two laminates of woven nylon (MB0130-023) and an outer laminate of polyvinyl film (MB0130-014) to act as a barrier against air permeability. The laminates are placed on the forming tool individually and visually examined for wrinkles prior to adding the next laminate. A vacuum of 26 inches of mercury is applied to the laminate composite to remove any entrapped air between

the laminates. The curing of the laminate facing sheet requires that the composite be held at a temperature of 340 F for 90 to 120 minutes. To prevent voids occurring between laminates and to allow normal removal of the reaction products, the temperature is applied over a period of 40 to 180 minutes. A vacuum of 24 inches of mercury must be maintained through the temperature cycle and until the composite has cooled down to a temperature of 150 F. Maintaining the vacuum till 150 F prevents excessive warpage of the composite. The vacuum system may be augmented with a pressure system. To prevent excessive squeeze-out of resin the combined vacuum and pressure systems cannot exceed 45 psi.

(b) Insertion of Foam Material: The foam (MB0130-015) is inserted into the honeycomb core (MB0130-014) by allowing the core cell walls to cut through the foam. The location of the foam in the thickness of the honeycomb core should be established to avoid interference with the dimpling of the face sheet. The dimpling in the face sheet stress relieves the bond between the face sheet and core during pressurization and tank structure expansion or contraction. At this time the grooves for distribution of the purge gas should be machined into the composite of foam and honeycomb core.

(c) Assembly of Details: Honeycomb core segments are nested or overlapped as shown in Figures 6.1.1.5-1 and 6.1.1.5-2 and bonded in place with either of the foaming-type adhesives (MB0120-014 or MB0120-030).

The face sheet is bonded to the honeycomb core using a heat curing adhesive (MB0120-048); the cure temperature of the composite is 335 F for 45 to 75 minutes. The curing temperature is reduced to 290 F when the face sheet is bonded to the core after the core has been bonded to the tank structure. The time at the reduced temperature is increased to 180 to 200 minutes. The reduction in temperature assures no reduction in the mechanical properties of the tank structure, for both temperature cycles a minimum of 20 inches of mercury is applied and held until the composite has cooled to a temperature of 150 F.

2. Installation of Basic Insulation Honeycomb Panel (MA0606-027)

(a) Prefit of Details: The panel faying surface is tailored to effect a honeycomb core-to-aluminum surface contact over the entire bonding surface. An impression check is made by substituting a 0.015-inch-thick Mosite sheet to represent the thickness of the adhesive.

(b) Prime Application: The surface of the metal structure is sprayed with an adhesive primer (MB0120-032) to an air-dry thickness of 0.5 to 1.5 mils. The primed structure is air-dryed a

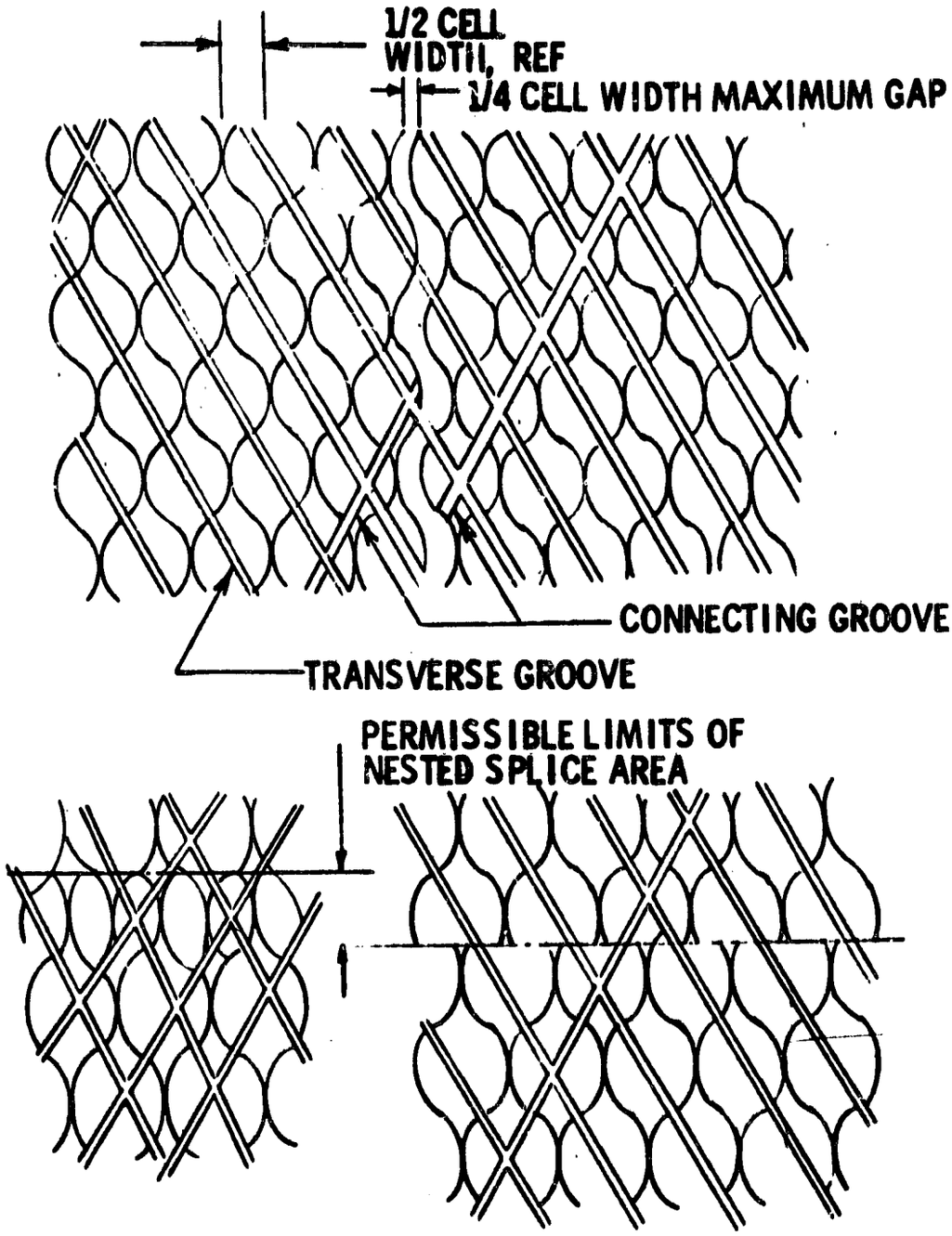


Figure 6.1.1.5-1. Purge Groove Patterns for Splice Areas

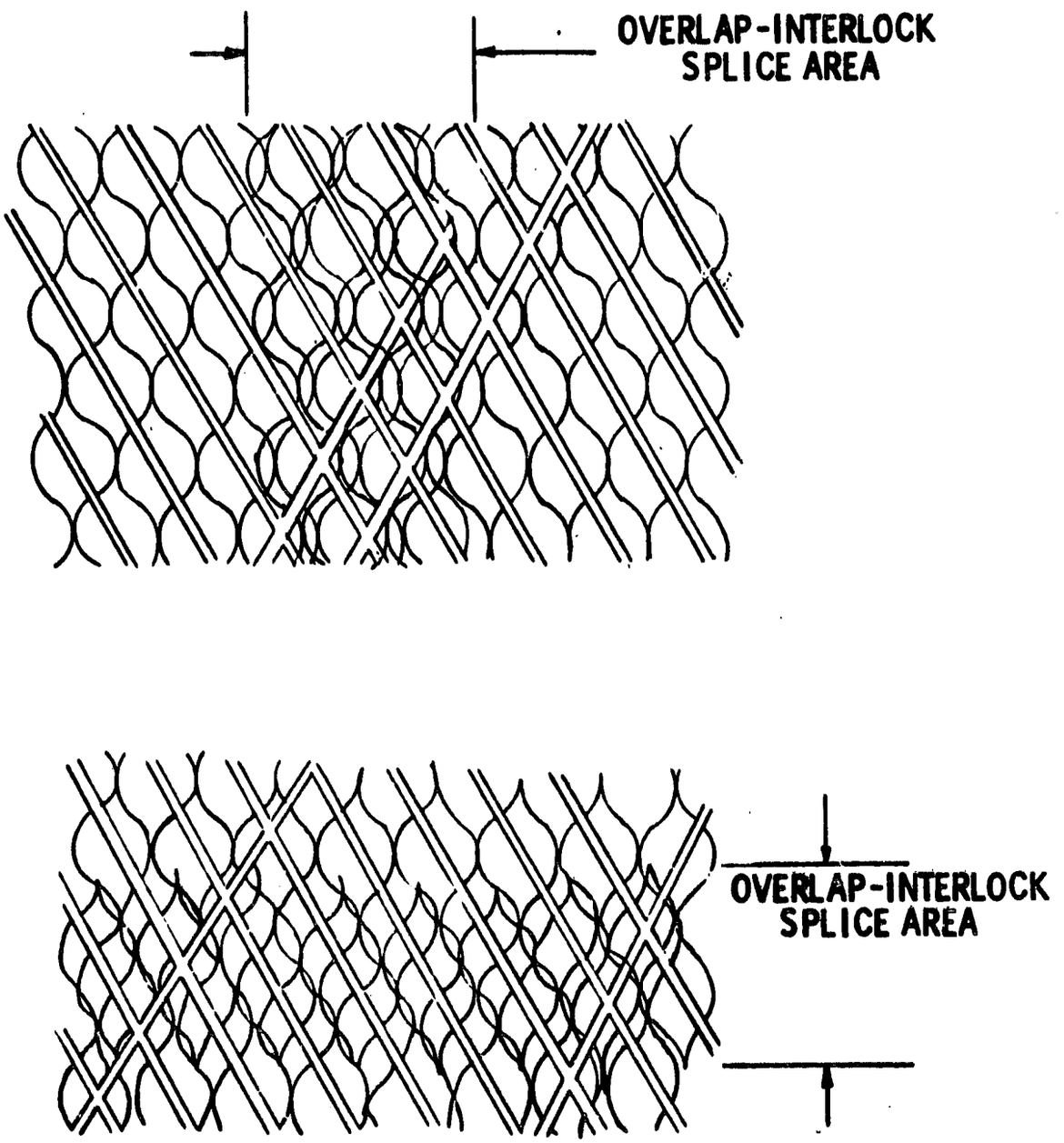


Figure 6.1.1.5-2. Transverse and Longitudinal Overlay-Interlock Splice Patterns

minimum of 30 minutes between coats. This is to permit evaporation of the solvent from the primer. The primer is cured for 180 minutes at a temperature of 290 F.

(c) Panel Installation: The panel is bonded to the tank structure with an epoxy adhesive (MB0120-048). The cure can be done in either an oven or autoclave. When the oven is used, a vacuum of 20 inches of mercury minimum is maintained. When the autoclave is used, the total pressure is maintained between 10 to 15 psi. Any combination of vacuum and augmented pressure may be used provided that a minimum vacuum of 5 inches of mercury is maintained to remove any outgassing products from the curing cycle. The cure temperature in either case is 290 F for 180 minutes and remains under pressure until cooled to a temperature of 150 F.

(d) Installation of Closeouts: The adhesive (MB0120-023) for bonding the closeout is applied to scrim cloth (MB0135-008) for adhesive thickness control. The net weight of the adhesive and scrim cloth must not exceed 0.28 gram per square inch. To assure proper adhesive wetting of the metal surface, a uniform coat of adhesive is applied prior to application of the adhesive-impregnated scrim cloth. The total weight of adhesive applied to the metal surface and scrim cloth is not to exceed 0.45 gram per square inch. The cure temperature of the closeout installation is 60 to 90 F for 48 hours while under a vacuum of 10 to 20 inches of mercury. The vacuum may be removed after 12 hours into the cure cycle.

3. Installation of Inserts (MA0606-027).

(a) Type I inserts are unthreaded steel spacers bonded to the tank wall with a polyurethane adhesive (MB0120-024).

(b) Type II Class I inserts are threaded steel inserts usually anchored into cast epoxy (MB0120-008).

4. Fabrication and Installation of Organic Edge Seal (MA0105-049):

(a) The organic edge seal consists of three laminates of woven nylon (MB0135-021). Each laminate is brushed with polyurethane resin (MB0120-024) before and after the addition of each layer to remove air bubbles and excess adhesive from the completed layup. A vacuum of 4 to 20 inches of mercury is applied and the areas carefully wiped with a cloth dampened with methyl-ethyl-ketone (MEK). The seal may be leak-checked after 48 hours at ambient temperature (70 F minimum); complete cure of the adhesive requires seven days at ambient temperature.

6.1.1.6 Manufacturing

a. General Description: The helium-purged, foam-filled phenolic honeycomb insulation is a relatively complex system of prefabricated and bonded composites that are joined by hot bonding using high-temperature curing (340 F) film type or pre-impregnated adhesives. These prebonded composite

subassemblies are bonded to the contoured quarter-panels of the tank wall prior to being welded into the tank cylinder using the same hot bonding adhesive system. The cylinder panels are approximately 80 inches wide by 26 feet long. The major portion of the S-II insulation was installed at the cylinder quarter-panel level because the high-temperature curing had to be accomplished in large temperature-controlled ovens. Panel sizes were generally dictated by material size limitations as well as size limitations of machine tools, processing tanks, ovens, and autoclaves.

Insulation for the forward bulkhead involves basically the same manufacturing steps except the mold line was more difficult to shape because of its compound contour. All honeycomb composites and subassemblies were bonded as gore segments in compound contour tools similar to the side panel tools. Final bonding of the gore-segmented composites was made to the total bulkhead at one time utilizing a large (36-foot diameter) clamshell autoclave and a tailored silicone rubber vacuum bag.

After tank assembly and weld joint inspection, insulation closeout panels, joint seals, doublers, and hard spots were bonded-in-place using various room-temperature curing liquid adhesives. These operations are somewhat simpler than the large panel installation because they required no high-temperature curing and were accomplished in localized areas by skilled hand layup mechanics.

Bonding pressure, when required by specification, was generally applied using vacuum-bagging techniques, making it possible to obtain even bonding pressure over the entire part up to approximately 14 psi. Pressure requirements in excess of 14 psi required use of an autoclave or mechanical pressure. The latter is not recommended unless there are no other alternatives. A manufacturing flow for the side wall operations is shown in Figure 6.1.1.6-1.

b. Tooling and Equipment: The primary tools required for this insulation system consist of bonding tools and trim and locating templates. Typical contoured bonding tools and curing oven used on the S-II program are shown in Figure 6.1.1.6-1. Flat panels and detail subassemblies were laid up and bonded using flat tooling plates.

Major equipment used was a large oven (15 by 12 by 30 feet) for side wall bonding and a 36 foot diameter clamshell autoclave for the bulkhead bonding.

6.1.1.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control:

1. Application of Primer (MB0120-032 and MA0106-045).

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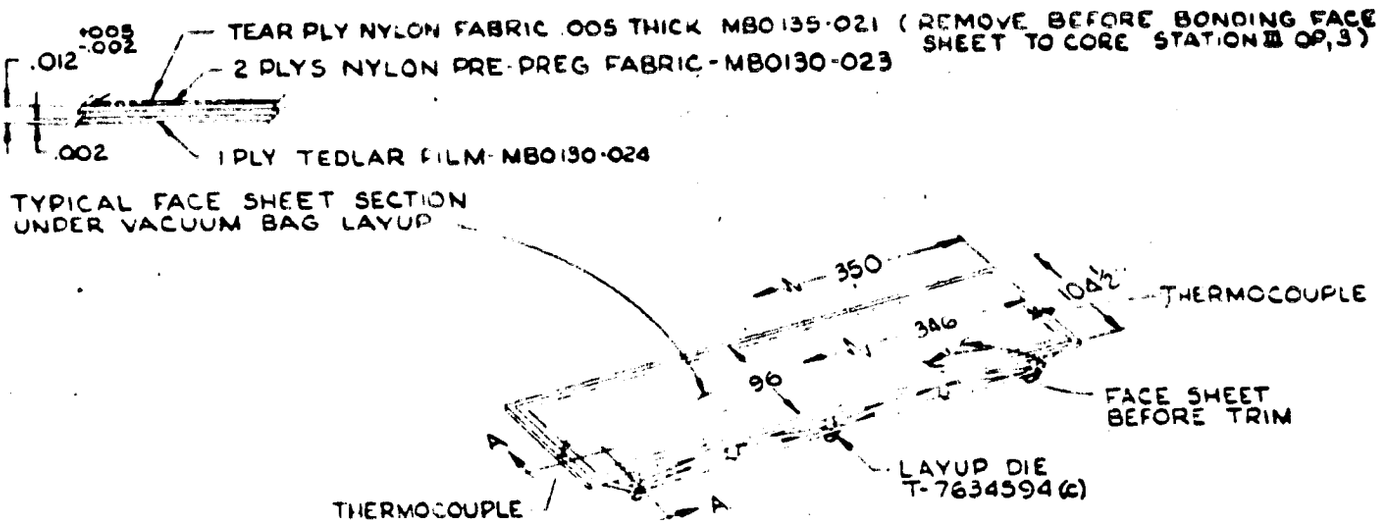
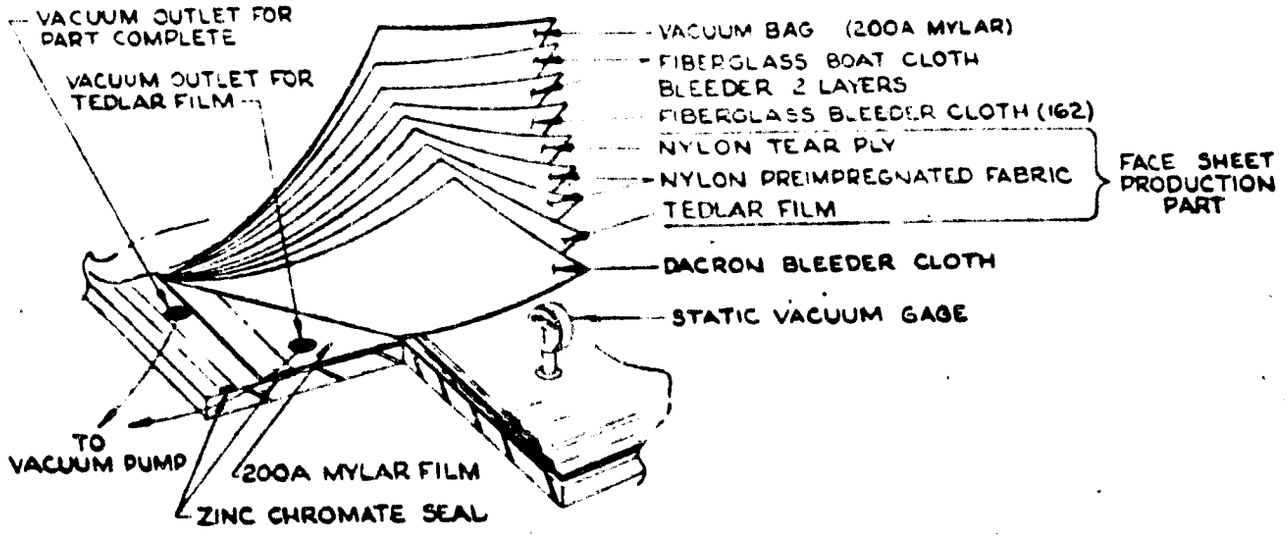
FAB FACE SHEET & DOUBLERS
TEDLAR - NYLON LAMINATES





SECTION A-A

1. LAYUP FACE SHEET LAMINATES AND APPLY VACUUM

FOLDOUT FRAME

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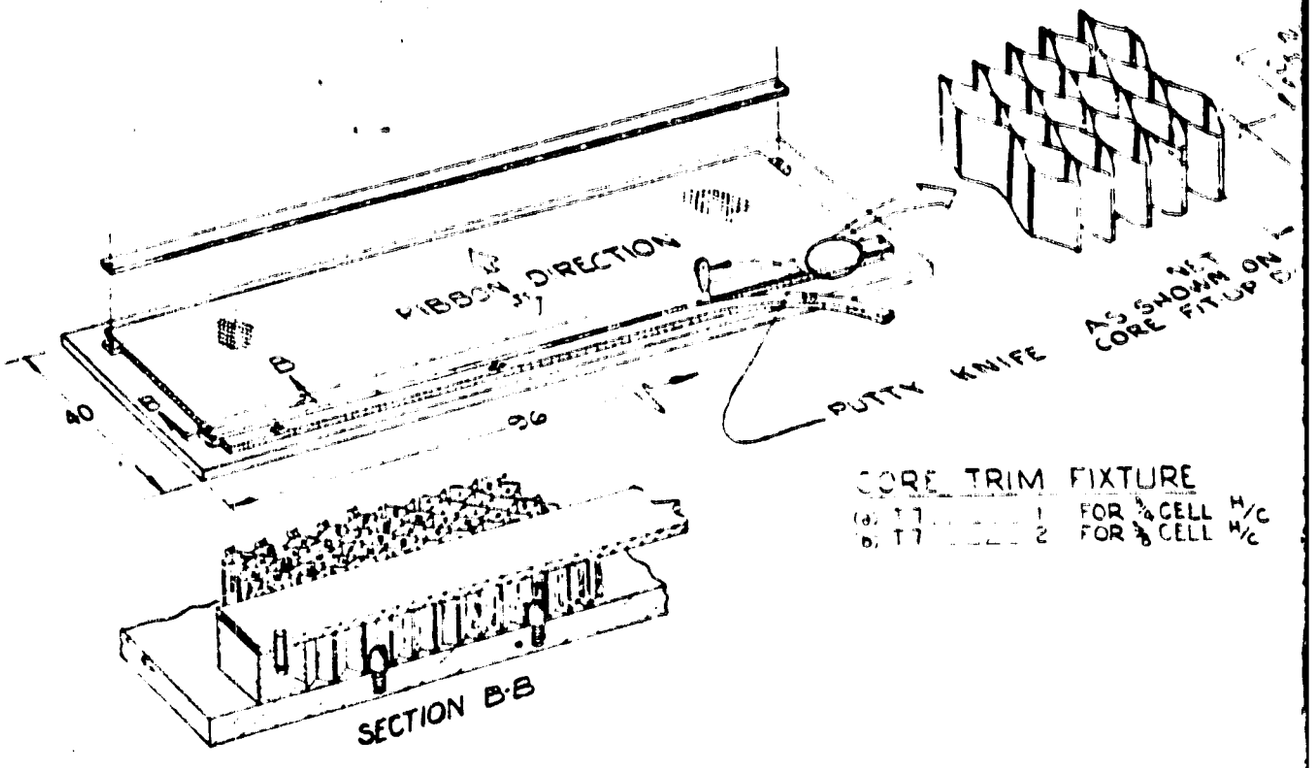
PREPARE CORE F

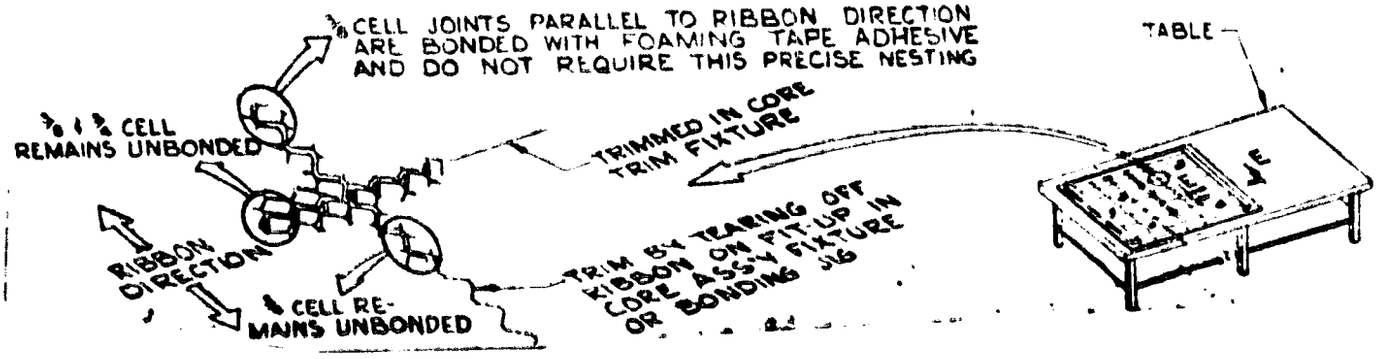
FACE
(0,3)

UPLE



CORE TRIM FIXTURE

(a) T1 ... 1 FOR ¾ CELL H/C
(b) T1 ... 2 FOR ⅜ CELL H/C



(2.) TRIM HONEYCOMB CORE PER DIMENSIONS OF ITEMS SHOWN ON CORE FIT-UP DIAGRAM

FOLDOUT FRAME 2

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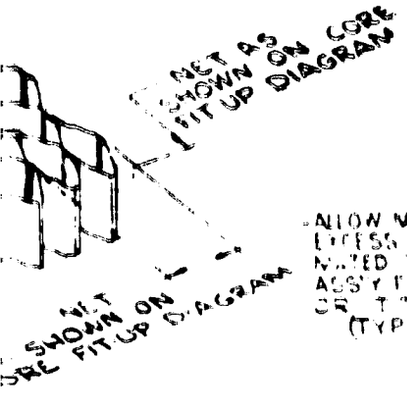
ORE BLANKET



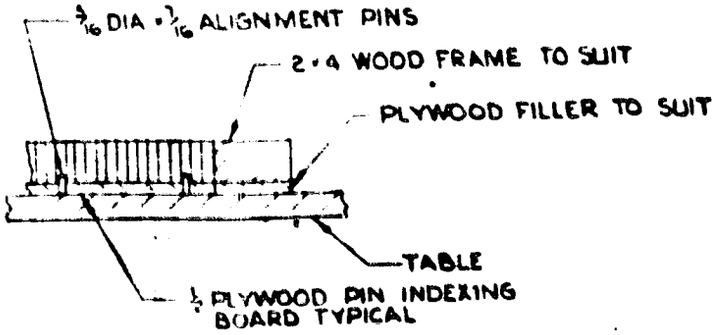
ALLOW MINIMUM OF 4 RIBBONS EXCESS FOR TEAR TRIM WHEN MATED TO ADJACENT CORE ON ASSY FIXTURE 1324212 (⅜ CELL) OR T" (⅝ CELL) (TYP BOTH ENDS)

¼ PLYWOOD PRESS

URE
⅜ CELL H/C
⅜ CELL H/C

CON

3.



SECTION E-E

ITEMS

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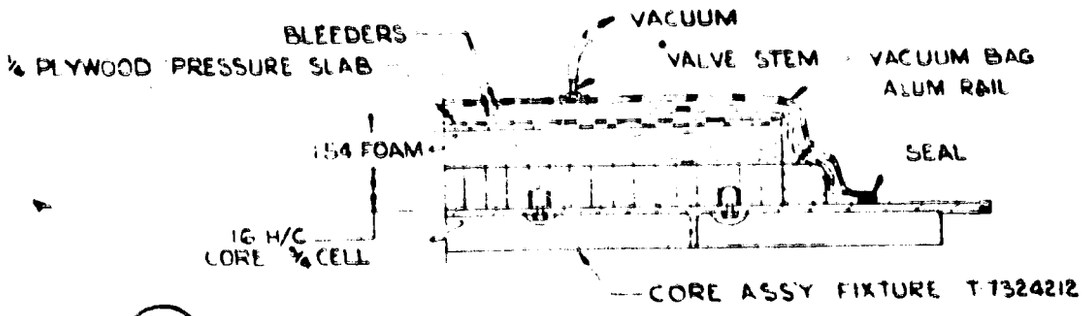

(3.) IMBED FOAM

FOAM BLOCKS PLACED OVER ASSEMBLED CORE AS SHOWN

STEP A. USE PLYWOOD PRESSURE SLAB - APPLY VACUUM & FORCE FOAM FLUSH TO CORE SURFACE.

STEP B. REMOVE PLYWOOD PRESSURE SLAB - REAPPLY VACUUM WITH BLEEDER CLOTH ONLY. THIS WILL SEAT FOAM IN PROPER POSITION FOR GROOVING

FOLDOUT FRAME 4

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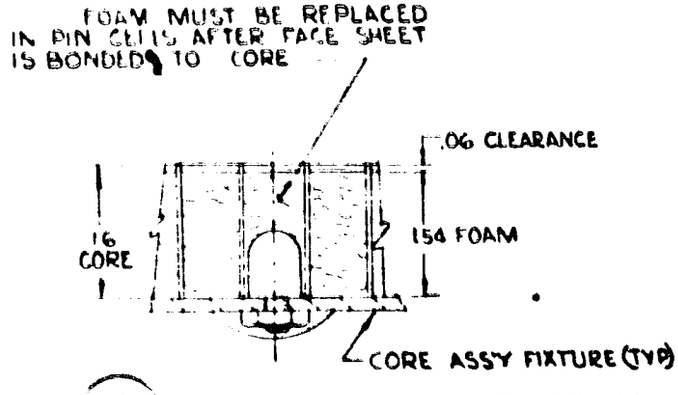


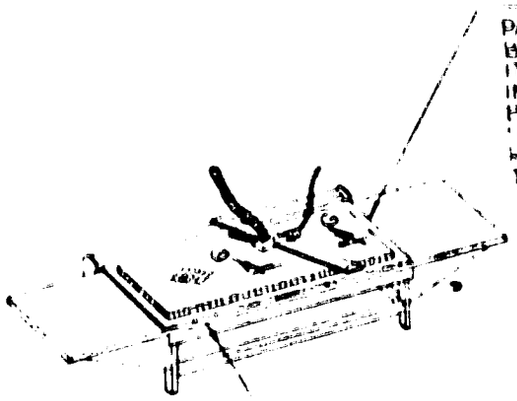
(4) IMBEDDED & SEATED FOAM

FACE.
NLY.

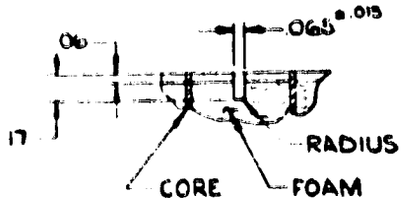
TYPICA
INDEXI

FOLDOUT FRAME 5

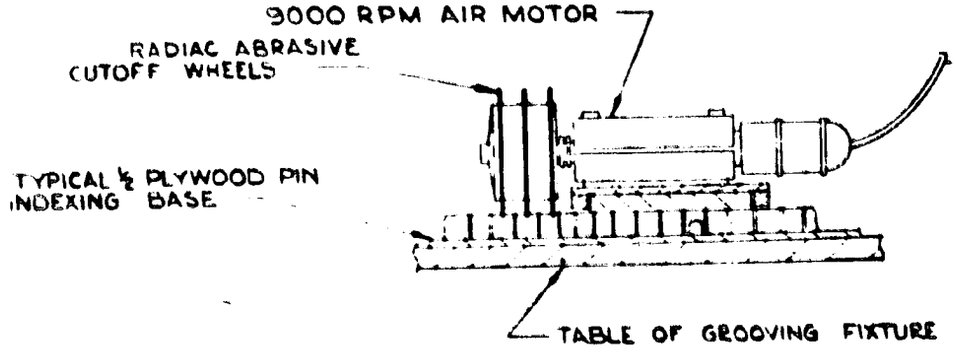
REMOVABLE ½ PLYWOOD PIN INDEXING BASE WITH SAME PIN PATTERN AS H/C CORE ITEM 1 ON T7624818 ASSY FIXTURE. THIS BASE WILL ALSO ACCOMMODATE ITEMS 2,3,4,6,7,8,10,11,12&13. THESE ITEMS HAND TRANSFERRED FROM T7624818 AFTER FOAM IMBEDMENT TO THIS BASE FOR ALL OTHER ITEMS, REMOVE THIS BASE AND USE ONE OF THE FOUR ½ PLYWOOD PIN INDEXING BOARDS SHOWN IN OPERATION 5 AS BASE. THESE ITEMS REMAIN ON THEIR RESPECTIVE PIN INDEXING BOARDS THRU THE FOAM IMBEDMENT (OP 5) AND GROOVING OPERATION



GROOVING FIXTURE
(b) T7634683



TYPICAL GROOVE DETAIL



SECTION G-G

5. GROOVE FOAM FILLED CORE

FOLDOUT FRAME 6

(6) BOND FACE SHEET TO CORE BLANKET

¼ CELL ½ INSERTED SECTIONS REQD
V7-590865-101 REQS (2) 13 SECTIONS
B64-101 REQS (1) 13 SECTION
201 REQS (1) - 13 SECTION
-301 REQS (1) - 13 (1) 21 SECTION
V7-592079-101 REQS (1) - 3 SECTION
080-101 REQS (1) - 2 3 (2) - 21 SECTIONS

ALL SECTIONS REQD FOR ONE SHIPS SET. MAKE FROM ITEMS 15 OR 16 CUT OUTLINE WITH STEEL RULE DIE.

TYPICAL ⅛ ½ INSERTED SECTION

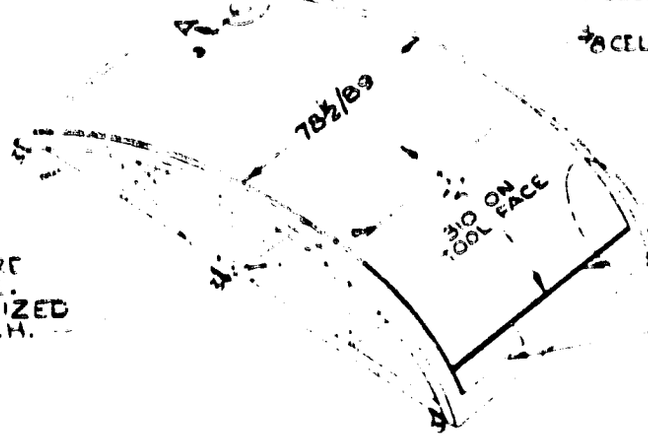
MB0120-014 FOAMING TAPE ADHESIVE

¼ CELL HONEYCOMB

STEEL RULE DIE CUT OUT TO OUTLINE ON JIG SURFACE (12 PCS PER SHIPS SET)

¾ CELL HONEYCOMB

⅛ CELL HONEYCOMB



TUNNEL ROW DETAIL

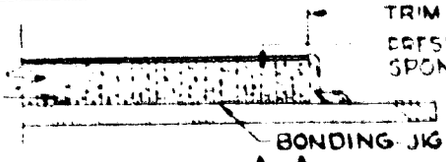
BONDING JIG T7634190 OR T7634731

OUTLINES OF ALL CORE DETAILS ARE SCRIBED ON BONDING JIG SURFACE. ASSEMBLE CORE DETAILS AS ITEMIZED ON CORE FIT UP DIAGRAM TO MATCH.

ALUMINUM PICTURE FRAME CLOSE OUT

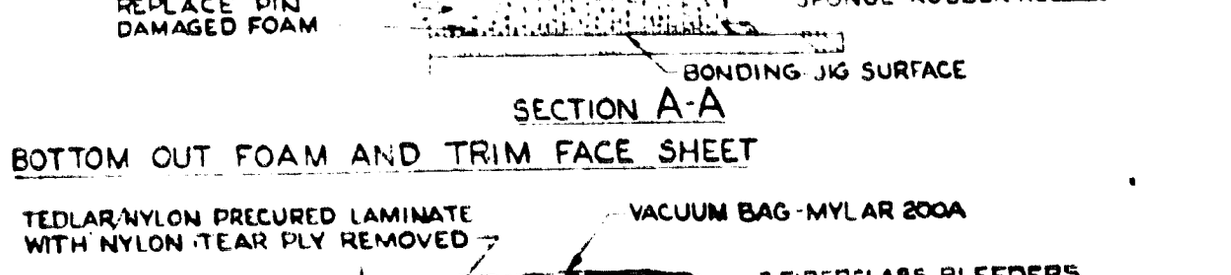
TEST SPECIMAN PROVIDES PANEL FOR PRESSURE TEST 5 FLATWISE TENSILE COU

(6a) ASSEMBLE CORE DETAILS ON BONDING JIG



SECTION A-A

(6b) BOTTOM OUT FOAM AND TRIM FACE SHEET



SECTION A-A

(6c) LAYUP ADHESIVES AND APPLY VACUUM

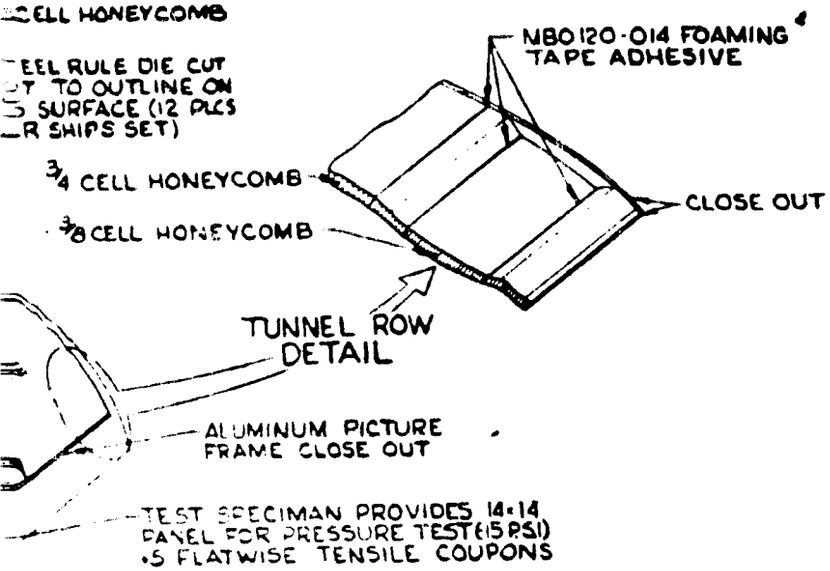
FOLDOUT FRAME 7

VKET

O-014 FOAMING
ADHESIVE

CELL HONEYCOMB

EEL RULE DIE CUT
T TO OUTLINE ON
S SURFACE (12 PLCS
R SHIPS SET)



SHEET

M DOWN WITH
UBBER ROLLER

ACE

OOA

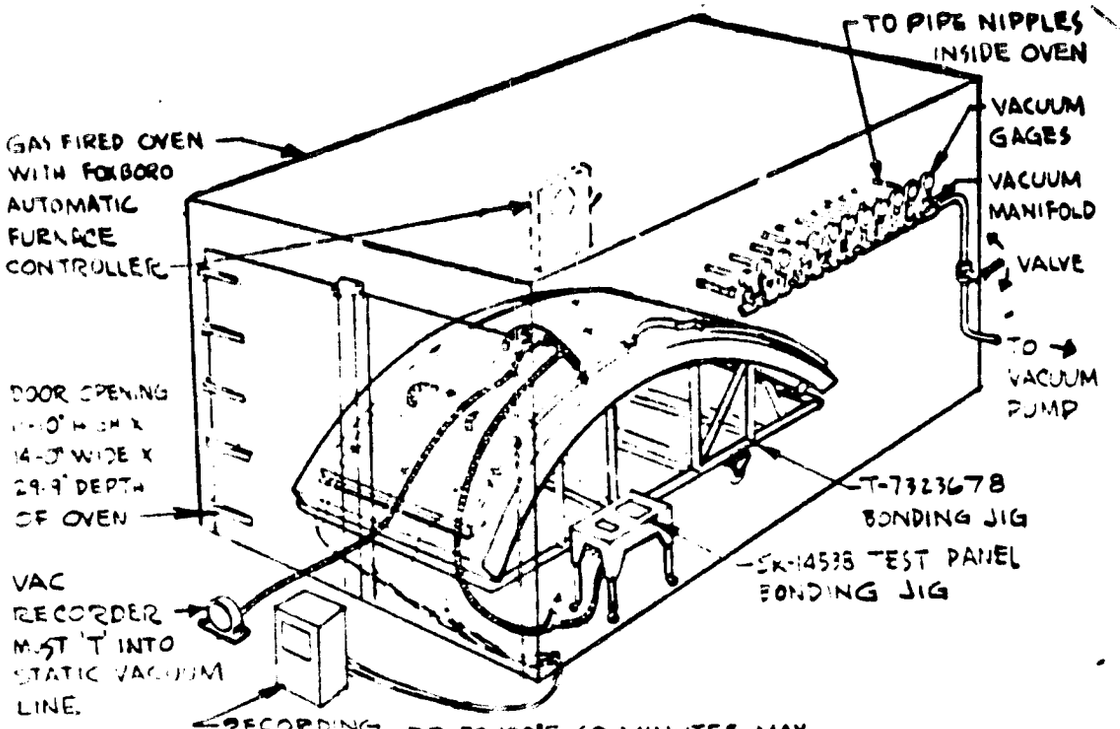
BLEEDERS
E) OUTER #162 (TOOLING)
ROMATE SEAL

Figure 6.1.1.6-1. Helium
Manuf

FOLDOUT FRAME 8

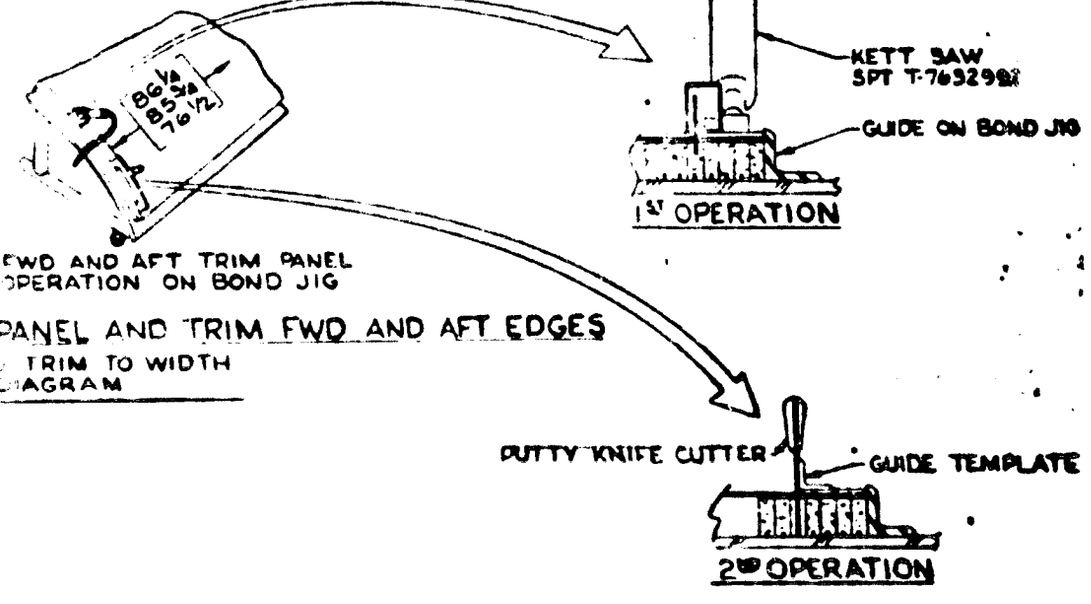
Figure 6.1.1.6-1. Helium Purged Insulation Honeycomb, Foam Filled Manufacturing Sequences
(Sheet 1 of 3)

FOLDOUT FRAME 9



RT TO 100°F 60 MINUTES MAX
100°F TO 260°F 30 TO 90 MINUTES
260°F TO 325°F 30 TO 90 MINUTES
335°F ±10°F 45 TO 75 MINUTES

7. OVEN CURE

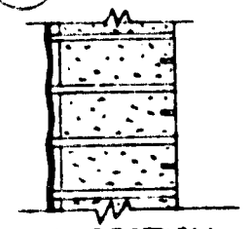


6. CLEAN UP INSULATION PANEL AND TRIM FWD AND AFT EDGES

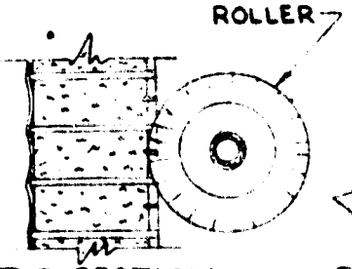
REMOVE BAG AND BLEEDERS TRIM TO WIDTH SHOWN ON ORIENTATION DIAGRAM

FOLDOUT FRAME

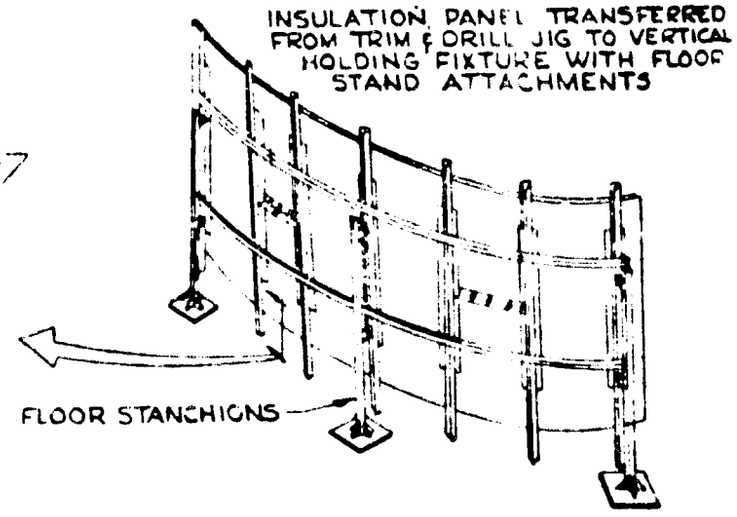
(9) TRIM SIDES



TYP SECTION
BEFORE ROLLING



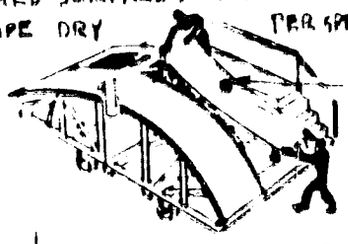
TYP SECTION
AFTER ROLLING

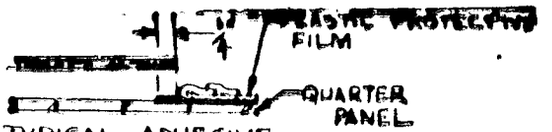


(10) SEAT FOAM WITH SPONGE RUBBER COVERED ROLLING PIN

T FRAME 2

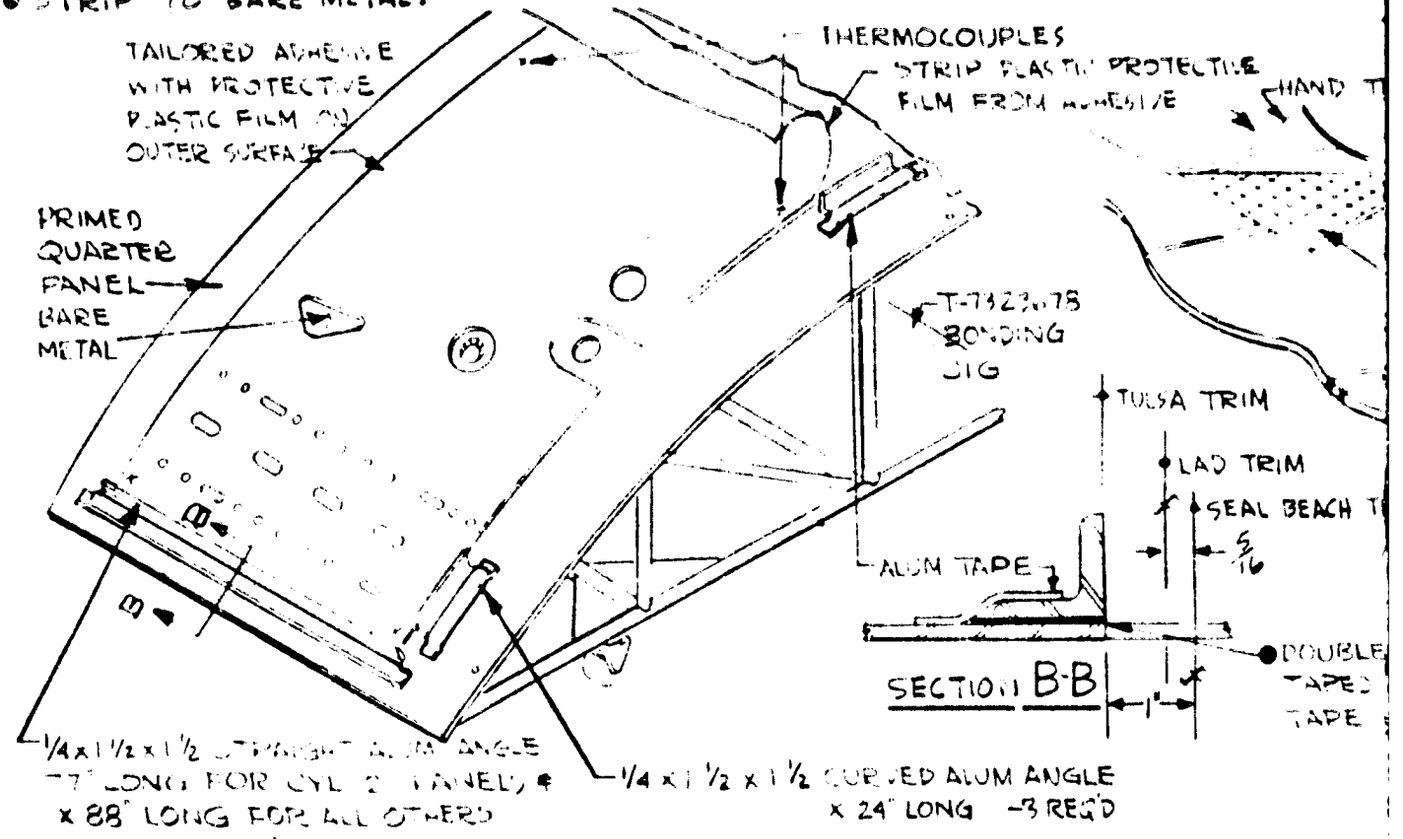
PRIMED SURFACE SOLVENT WIPE WITH MEK ℓ WIPE DRY PER SPEC MA0120-048

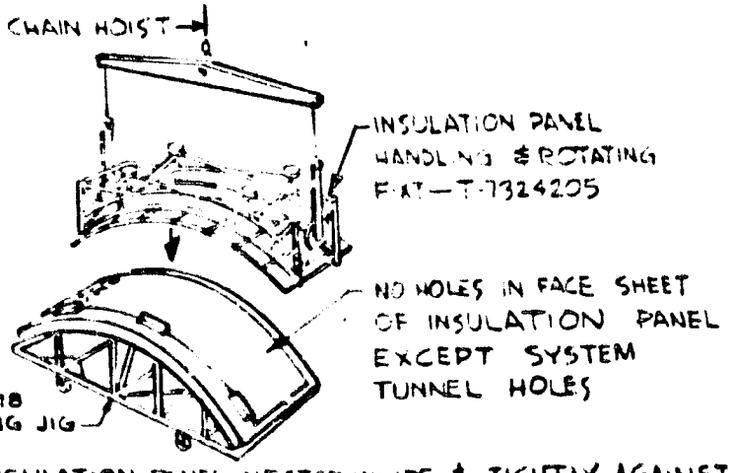


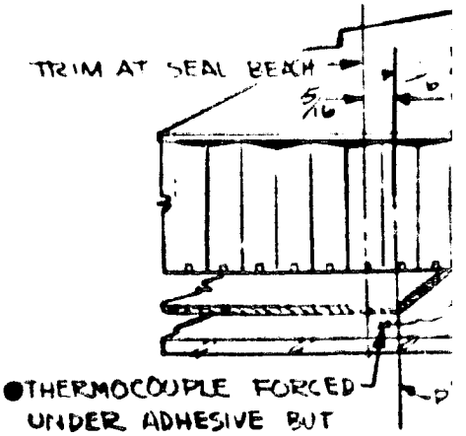


TYPICAL ADHESIVE OVERLAP

- LAYUP TAILORED ADHESIVE OVER MISMATCH AREAS IF REQUIRED (REFER TO STATION K, STEP 3
- CUT 153" LENGTHS FROM 36" WIDE ROLL OF ADHESIVE. STRIP PLASTIC PROTECTIVE FILM FROM ONE ADHESIVE SURFACE & COVER ENTIRE PRIMED SURFACE. ALLOW ½" MIN. ADHESIVE OVERLAPS. COVER MISMATCH ADHESIVE LAYU
- CUT THRU OUTER PLASTIC PROTECTIVE FILM & ADHESIVE AT OUTLINES OF ALUM. TAPE MASKANTS. STRIP TO BARE METAL.







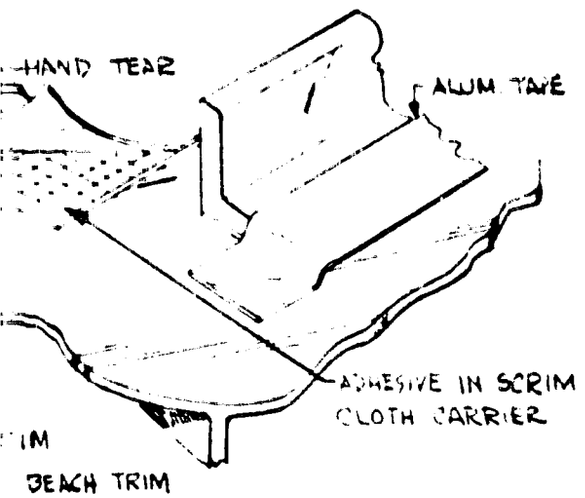
- THERMOCOUPLE FORCED UNDER ADHESIVE BUT NOT INSIDE SEAL BEACH T

FOLDOUT FRAME 3

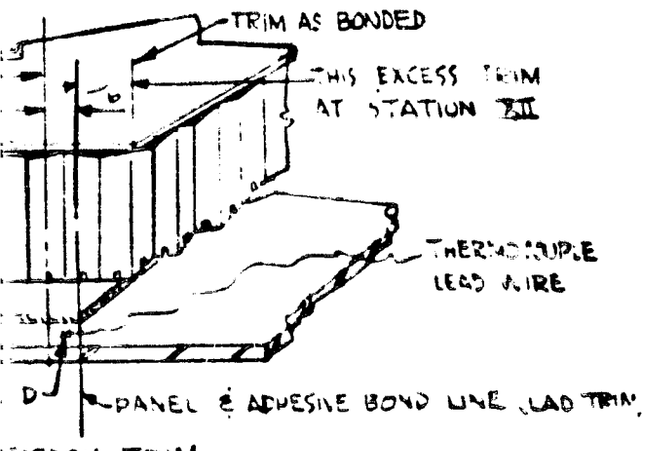
- INSULATION PANEL NESTED INSIDE & TIGHTLY AGAINST ALUMINUM ANGLE STOPS AS IT IS LOWERED WITHIN HANDLING FIXTURE. TAPE STRIPPED FROM VAC

LAYUP ADHESIVE MB0120-048 TYPE II (424 TYPE II)

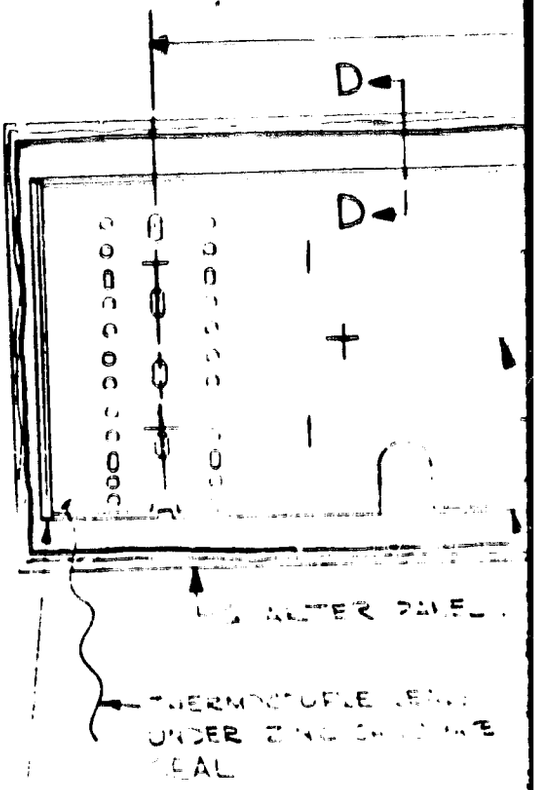
IVE LAYERS
ANTS.



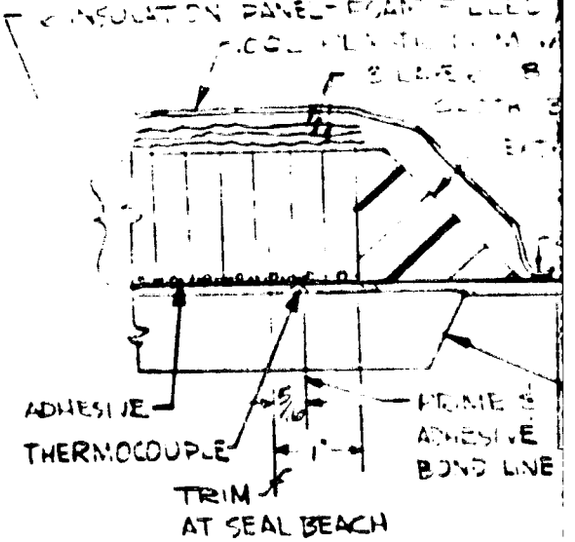
DOUBLE BACK TAPE ALIGNED BETWEEN TAPED SPOTS OF STEP '2' PLUS ALUM TAPE HOLDS ANGLE IN POSITION



FOLDOUT FRAME 4

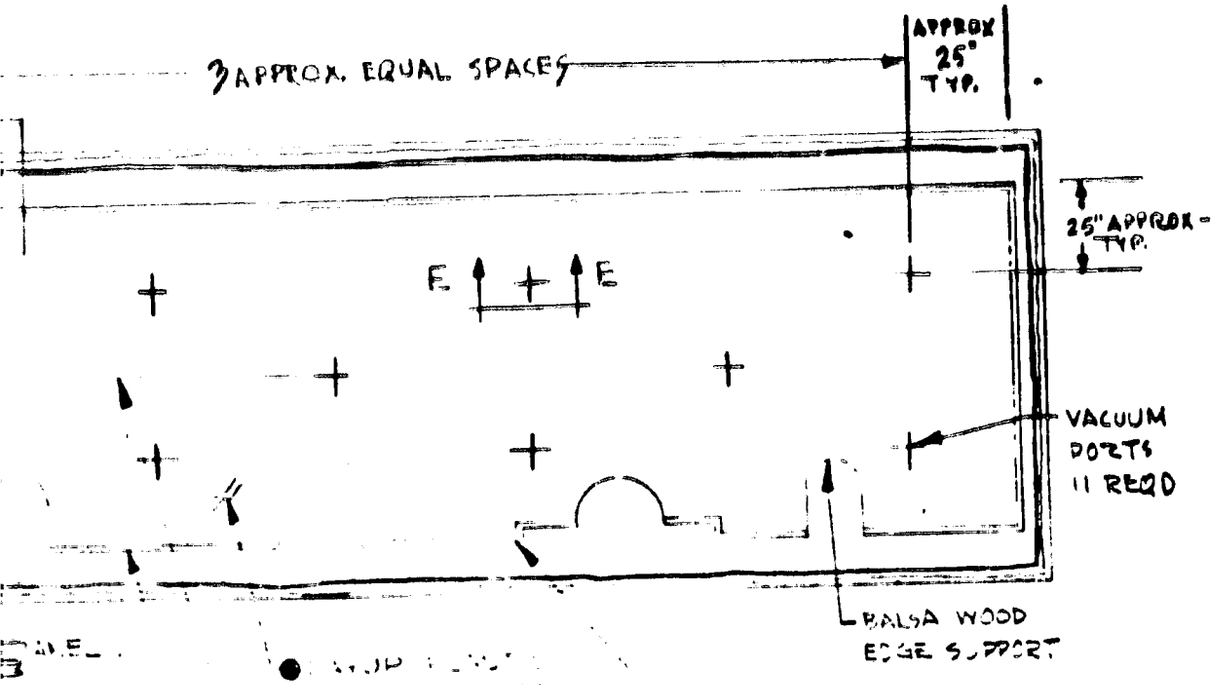


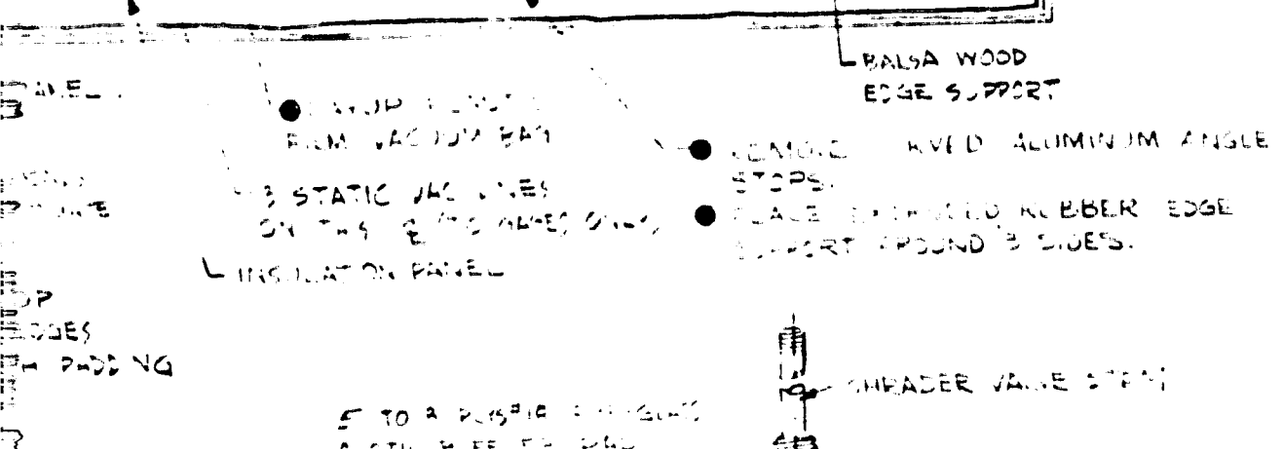
ALUMINUM ANGLE STOP
PROTECT ALL SHARP EDGES WITH FIBERGLASS CLOTH PADS

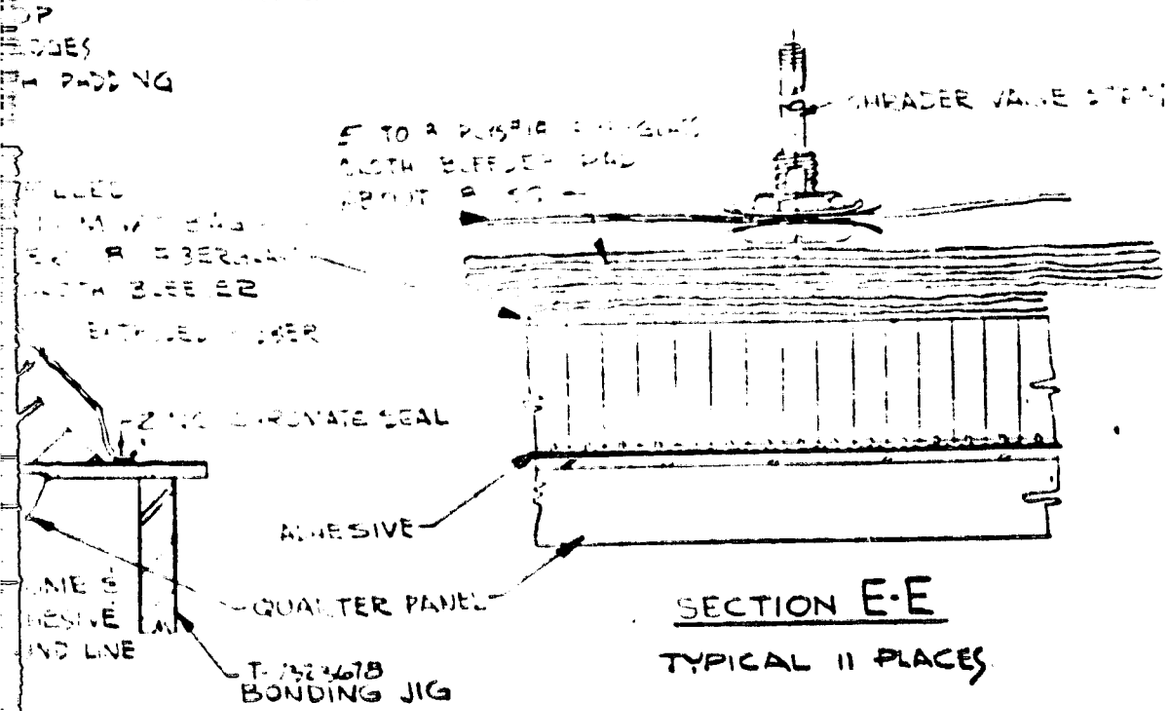


SECTION D-D
TYPICAL ALONG 3 SIDES

(12) SEAL IN VACUUM BA







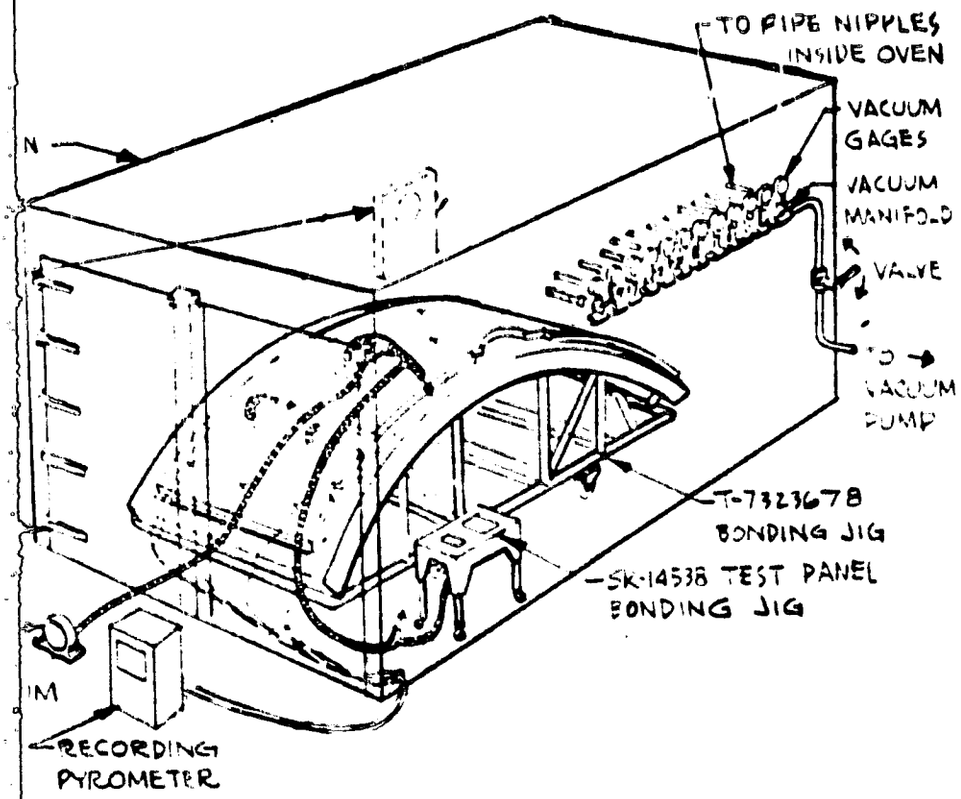
SECTION E-E

TYPICAL 11 PLACES

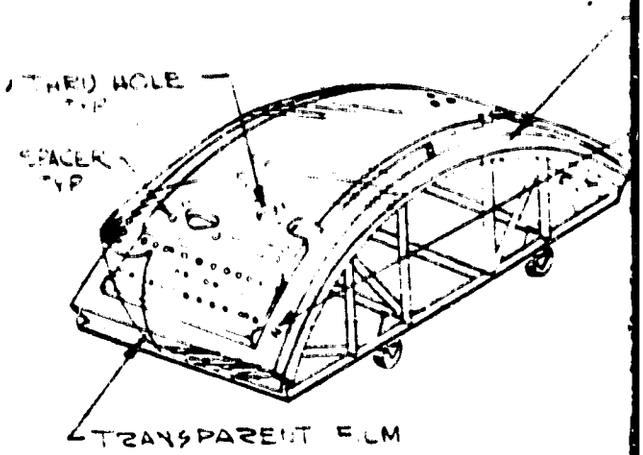
M BAG

FOLDOUT FRAME 5

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

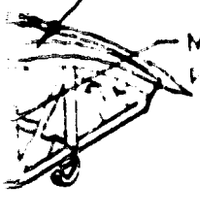


13 OVEN CURE



14 LOCATE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.



—FLEXIBLE MYLAR FILM TEMPLATE WITH LAYOUT OF ALL HOLES & PRICK PUNCH MARKS AT ℄ OF EVERY THREADED INSERT AS PREPARED IN STATION II STEP ②

—MYLAR FILM TEMPLATE RESTS ON TOP OF L6 INSULATION PANEL # 5 LOCATED OVER L4 DIA COORDINATION HOLES.

OCATE HOLES FROM TEMPLATE

Figure 6.1.1.6-1.

FOLDOUT FRAME 7

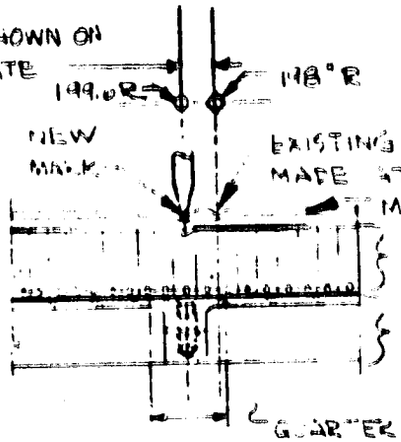
REPRODUCIBILITY OF THE ORIGINAL PAGE

Figure 6.1.1.6-1. Helium Purged Insulation Honeycomb, Foam Filled Manufacturing Sequences
(Sheet 2 of 3)

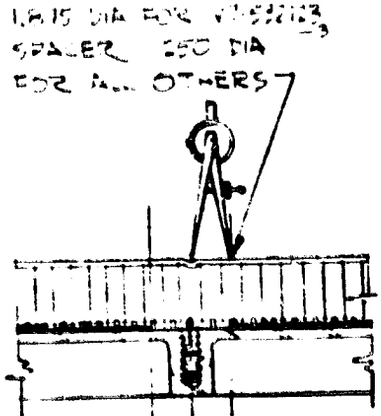
FOLDOUT FRAME 8

SPACER PROCEDURE

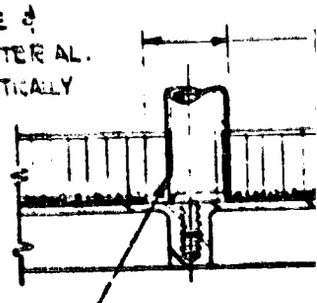
- PRICK PUNCH WITH HAND SCRIBE & INTERSECTIONS ON MYLAR FILM TEMPLATE & PIERCE INSULATION PANEL FACE SHEET. MAINTAIN SLIGHT MISLOCATIONS IF ANY, INDICATED BY EXISTING PUNCH MARKS.



- REMOVE MYLAR FILM TEMPLATE. SET ONE LEG OF SHARP POINTED DIVIDERS IN PIERCED HOLE & ROTATE SWING POINT UNTIL TEDLAR-NYLON FACE SHEET IS CUT THRU THEN TEAR OUT FACE SHEET PLUG.



- CUT & REMOVE EXPOSED HONEYCOMB CORE & FOAM FILLER MATERIAL. HAND PLUNGE VERTICALLY WITH A TUBULAR CUTTER.



(15) CUT HOLES IN INSULATION - REQUIRED ON CYLINDERS 2 & 3 PANELS O

FOLDOUT FRAME

STEP (2)

STEP 3

1615/1.250

EEL TUBULAR
TTER WITH
RNED INSIDE
TTING BEVEL

PANELS ONLY

SPACER BONDING

- ASSEMBLE SPACER ON CLAMP SCREW & WASHER.
- SPATULA COAT SIDES & BOTTOM OF SPACER WITH 7343 ADHESIVE. KEEP CLAMP SCREW THREADS FREE OF ADHESIVE.
- THREAD CLAMP SCREW INTO TAPPED PANEL & TORQUE TO [illegible] IN-LB MINIMUM

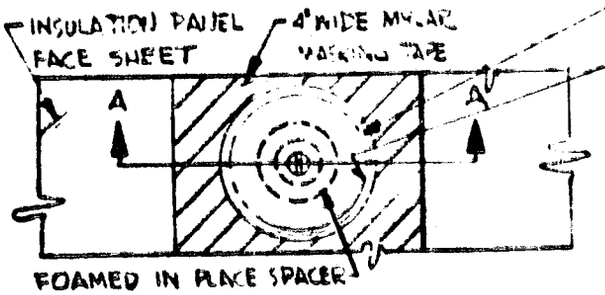
SPACER FOAMING

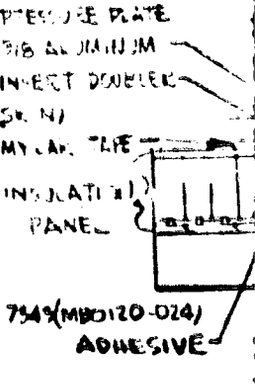
- "C" CLAMP THERMOCOUPLE TO AN EDGE OF PANEL AT SIDE OF BOSS.
- PRE-HEAT BOSS WITH ELECTRIC HOT AIR HEAT GUN.
- MAINTAIN 5'' F OF UNTIL FOAMING ACTION STOPS. REQUIRES 1 TO 3 MINUTES FROM START OF HEAT TO COMPLETION OF FOAMING ACTION.
- MIX & POUR FOAM ADHESIVE MBO130-024, HAND POUR FROM SMALL ALUMINUM FOIL CUP. IMMEDIATELY UPON COMPLETION OF POUR PLACE TEFLON PLATE OVER CAVITY HOLE IN PANEL FACE SHEET BY HAND, AGAINST INSULATION PANEL FACE SHEET UNTIL FOAMING ACTION STOPS. REQUIRES [illegible] MINUTES.
- COVER WITH 2" ALUMINUM PRESSURE TAPE AT LEAST 1" BEYOND TEFLON PLATE. ALUMINUM TAPE & TEFLON PLATE CAN BE REMOVED AFTER 4 HRS ROOM TEMPERATURE CURE.
- CLAMP SCREW & WASHER CAN BE REMOVED AFTER 24 HRS ROOM TEMPERATURE CURE.

CLAMP SCREW #7-532-2203

[illegible] "F
[illegible] IN
FOR .750
2.50 IN
FOR OTHE
ALUM TAPE

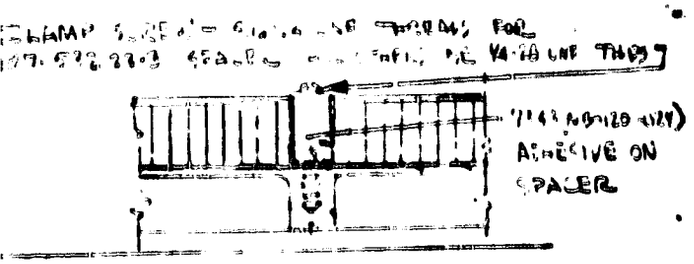
ELECTRIC
HOT AIR
PREHEAT BOSS TO

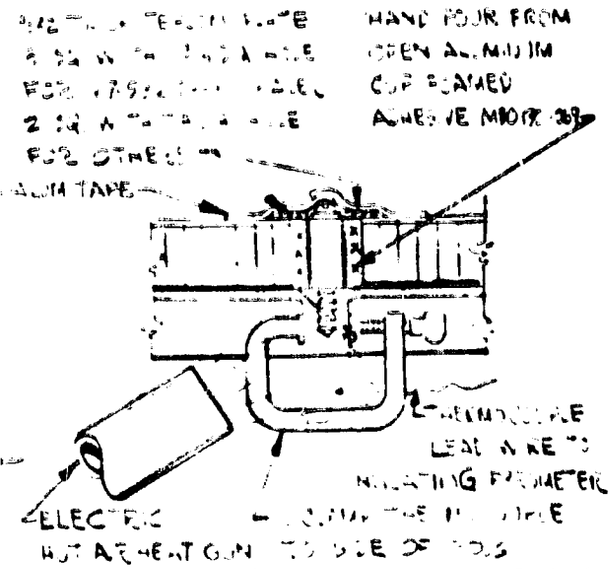


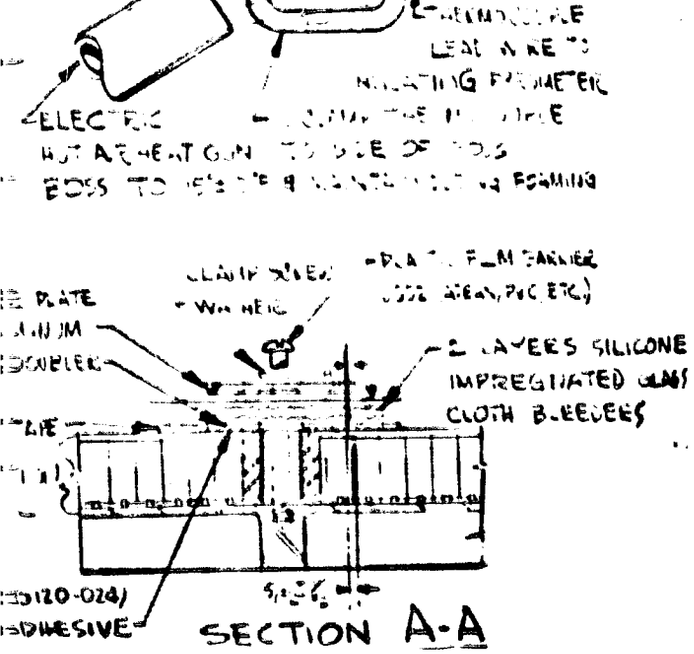


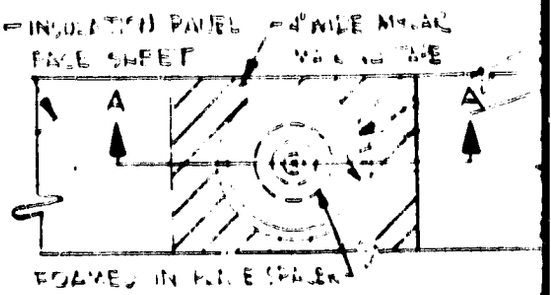
(16) BOND & FOAM IN PLACE SPACER

FOLDOUT FRAME 2





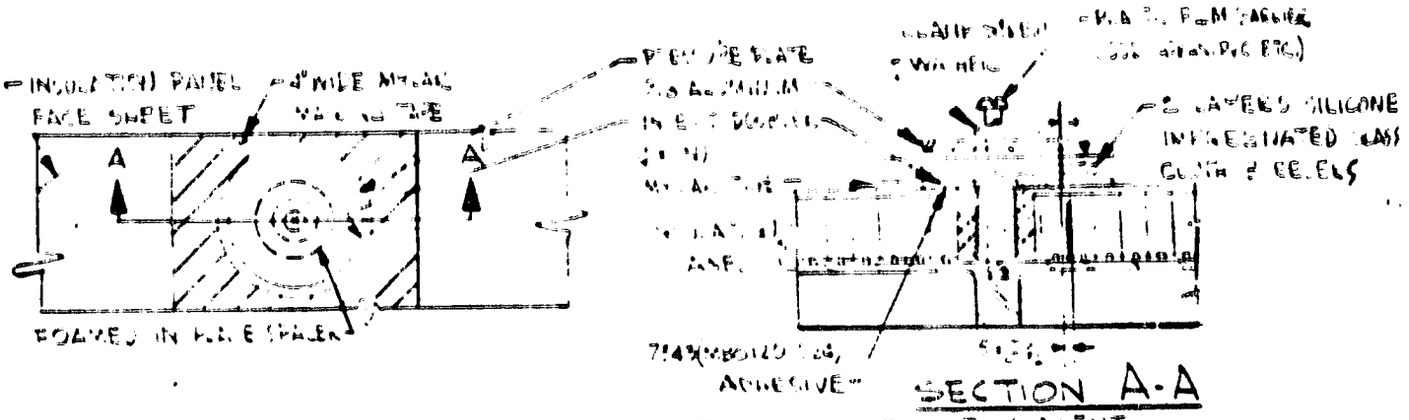




- COAT CLAMP SCREWS
- LIGHTLY ABRADE
- MIX MBO
- SPREAD 4" WIDE MYLAR MASKING
- PLACE MYLAR TAPE MASK ON IN
- SPATULA COAT BOTH FAYING
- POSITION INSERT DOUBLER ON
- LAYUP BLEEDERS,
- LAYUP TOOLING (CLAMP SCREW,

17. BOND SKINS (INSER

PER SPEC MA0606-039-"1

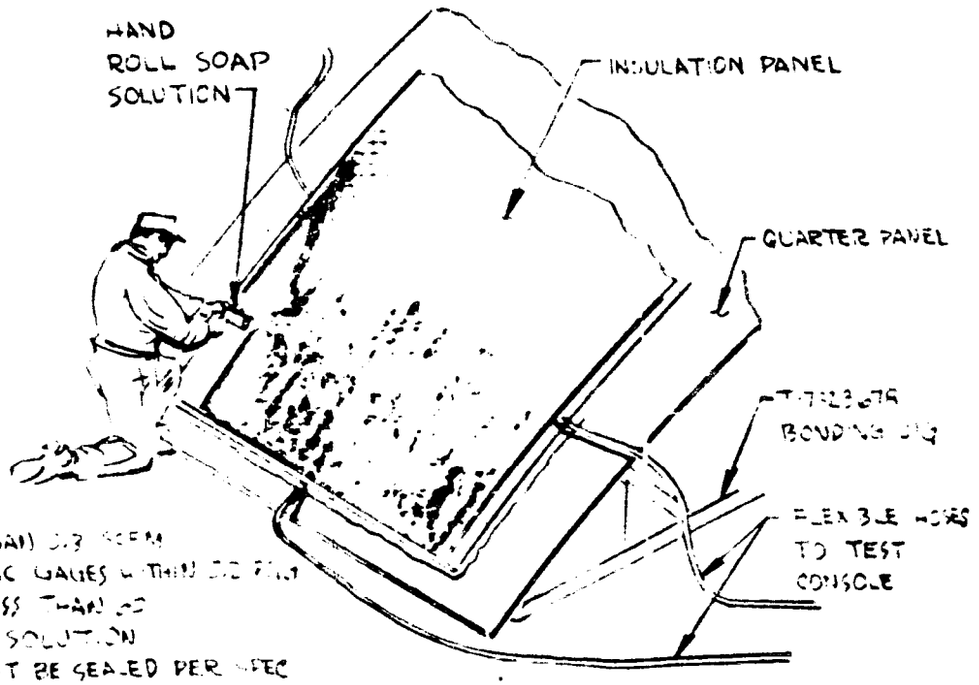


- COAT CLAMP SCREW, WASHER & ALUM. PRESSURE PLATES WITH RELEASING AGENT.
- LIGHTLY ABRADE, CLEAN WITH MEK & WIPE DRY FAYING SURFACES (DOUBLER & INSULATION PANEL)
- MIX MBO [illegible], VARNCO 7343, ADHESIVE.
  ADHESIVE MUST BE APPLIED WITHIN 40 MINUTES AFTER MIXING.
- SPREAD 4" WIDE MYLAR MASKING TAPE ON PIECE OF SCRAP ALUMINUM SHEET.
  CUT OUTLINE OF INSERT DOUBLER 5.32 ARDEA ALL AROUND THRU THIS TAPE.
  USE SHARP POINTED DIVIDERS & STANLEY KNIFE.
- PLACE MYLAR TAPE MASK ON INSULATION PANEL SURFACE SO THAT HOLE IS CENTERED OVER SPACER
- SPATULA COAT BOTH FAYING SURFACES WITH 7343 ADHESIVE
- POSITION INSERT DOUBLER ON INSULATION PANEL SURFACE WITH HOLE IN INSERT DOUBLER CONCENTRIC WITH SPACER.
- LAYUP BLEEDERS, PLASTIC FILM BARRIER, PRESSURE PLATE & TIGHTEN CLAMP SCREW TO 15-20 INCH-POUNDS OF TORQUE
- LAYUP TOOLING (CLAMP SCREW, ETC.) CAN BE REMOVED AFTER 24 HOUR ROOM TEMPERATURE CURE.

(17.) BOND SKINS (INSERT DOUBLERS)

PER SPEC MA0606-039-"INSTALLATION OF INSERTS IN CRYOGENIC INSULATION-"SATURN S II"

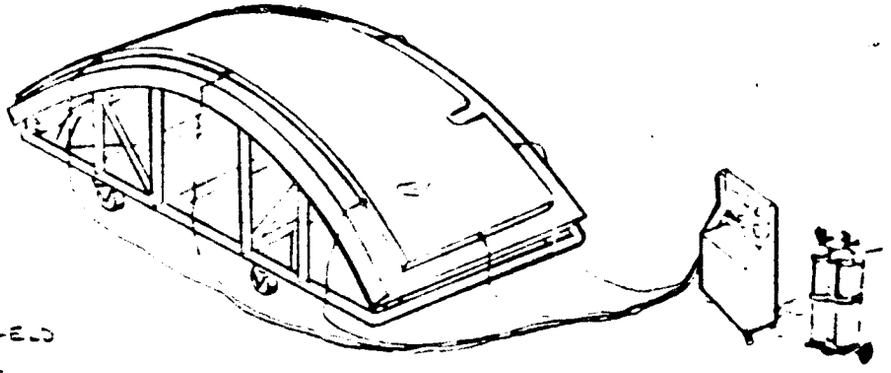
- APPLY GAS PRESSURE IN 0.5 PSIG INCREMENTS.
- MAINTAIN CAREFUL VISUAL INSPECTION OF ENTIRE INSULATION PANEL SURFACE AT ALL TIMES FOR ANY EVIDENCE OF DISBONDS.
- STABILIZE ALL 4 STATIC GAGES @ 1.5 ± 0.2 PSIG WITH LESS THAN 0.3 SCFM FLOW OF NITROGEN GAS. ROLLER COAT SOAP SOLUTION LEAK TEST COMPOUND MIL-L-25567, TYPE 1 SOLUTION.
- APPLY SOAP SOLUTION AT RATE OF LESS THAN 4 SQ FT PER MINUTE & OBSERVE ANY BUBBLE FORMATION.
- LEAKS ARE INDICATED BY
  1. INABILITY TO ACHIEVE FLOW RATE LESS THAN 0.3 SCFM
  2. INABILITY TO STABILIZE ALL 4 STATIC GAGES WITHIN 30 PSIG
  3. FORMATION OF SOAP BUBBLES IN LESS THAN 30 SECONDS FROM APPLICATION OF SOAP SOLUTION
- NO LEAKS ARE PERMITTED. LEAKS MUST BE SEALED PER SPEC MA0306-1027 & PASS THIS LEAK CHECK BEFORE PANEL CAN BE PROOF PRESSURE TESTED.



18 LEAK CHECK ENTIRE INSULATION PANEL SURFACE @ 1.5 PSIG

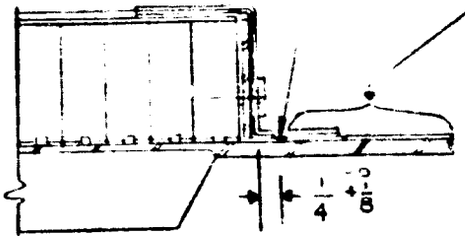
LDOUT FRAME 5

- IF NO LEAKS OTHER THAN MINOR PINHOLES WERE FOUND IN STEP 2 ABOVE, CONTINUE PROOF PRESSURE TESTING AT 1.5 PSIG, OTHERWISE START PROOF PRESSURE TESTING AT 0.5 PSIG.
- INCREASE PRESSURE BY 0.5 PSIG INCREMENTS TO 5 PSIG
- EACH INCREMENT SHALL BE MADE WITHIN 3 MINUTES & HELD FROM 2-5 MINUTES.
- AFTER EACH INCREMENT THE PRESSURE SHALL BE STABILIZED TO ± 0.3 PSIG.
- AT EACH PRESSURE STABILIZATION LEVEL A RECORDING OF EACH PRESSURE GAGE & THE TOTAL RATE OF FLOW SHALL BE MADE.
- THE FINAL 5 PSIG PRESSURE LEVEL SHALL BE HELD FOR 15 MINUTES THEN PANEL VENTED RAPIDLY.



(19) PROOF PRESSURE TEST

- CUT UP P AND TRIM A RE FOR STRAIGHT TRIMS, USE HOT KNIFE FOR CURVED



RE-CHEM-FILM PER MIL-M-3171 TYPE I APPLICATION OF CHEMICAL FILM TO ALUMINUM ALLOYS" - BRUSH COAT

- SOLVENT CLEAN MEK/MPK WIPE DRY
- DETERGENT WIPE
- TAP WATER RINSE
- BRUSH ON DEOXIDIZER
- TAP WATER RINSE
- CHEM-FILM, BRUSH COAT ALODINE 1200
- TAP WATER RINSE.
- AIR DRY, ROOM TEMP

REMOVE ALL SHOP AID MOLD PLUGS & RPT. PLUG T-7324267 & SEAL EXPOSED FOAM WITH MARMON 7343

(20) TRIM EDGE SEAL & RE-CHEM-FILM

Figure 6.1.1.6-1. Helium Purged Insulation Honeycomb, Foam Filled Manufacturing Sequences
(Sheet 3 of 3)

FOLDOUT FRAME 7

(a) Surface Preparation: All cleaning solutions and facilities were verified to be within specification requirements and functional prior to each cleaning operation (MA0610-002). Final verification of proper surface preparation was made by pH test and verification of a water break-free surface.

(b) Application: Prior to elevated temperature curing, primer thickness was verified by the use of a Fischer Permascope.

(c) Adhesion: Process verification coupons were processed simultaneously with the production part. Lap shear strength (using production adhesive) was verified.

2. Fabrication of Basic Insulation Details (MA0605-003).

(a) Visual Inspection: All finished details were visually inspected for:

(1) Proper dimpling of facing laminate

(2) Barrier film holes

(3) Broken nodes

(4) Unfilled core cells

(5) Foreign objects

(6) Wrinkles

(7) Core/laminate voids

(b) Coupon Proof Pressure: A test coupon with a minimum unrestrained test area of 12 inches by 12 inches minimum, was fabricated simultaneously with the production part. The coupon was pressurized to 15.5 ± 0.5 psi and held for 15 minutes.

(c) Subassembly Proof Pressure (MA0201-1930): Following successful testing of the coupon, the production subassembly was pressurized with nitrogen gas. The subassembly was pressurized to 1.5 psig and a bubble fluid leak check was performed. The part was subsequently pressurized to 15 psig and held for 15 minutes.

3. Installation of Standoff Spacers and Threaded Inserts, (MA0606-039).

(a) Visual Inspection: Inspection was limited to routine verification of proper adhesive-foam mix, cure cycle minitoring, and dimensional verification.

(b) Leak Check: Completed installations were pressurized and leak-checked, using the bubble fluid technique, (MA0615-003).

(c) Torque Test: Threaded inserts were torque-tested with the maximum installation bolt torque.

4. Installation of Organic Edge Seals, (MA0105-049):

(a) Visual Inspection: Installations were verified to be free of holes, fractures, blisters, delaminations, resin-starved areas, and foreign inclusions.

(b) Leak Check: Completed installations were pressurized and leak-checked, using the bubble fluid technique.

5. Installation of Insulation Closeouts, (MA0606-027):

Visual Inspection: Process control and visual inspection were essentially identical with those described previously. The significant difference was that closeouts were associated with structural weld joints which had been left exposed for inspection following pneumostat of the tank structure. Because of surface irregularities associated with welds, each section of closeout insulation was subjected to a Mosites 1440 silicone rubber impression check. A uniform "footprint" was required prior to final bonding operations.

c. System Checkout, (MA0201-4265): Following completion of all subassembly installations and insulation closeouts, the entire basic insulation composite was subjected to a final functional checkout. The inspection sequences consisted of a comprehensive visual, vacuum bell test of suspect areas, leak check, flow check, proof pressure test, and final leak check and visual inspection.

1. Vacuum Bell Inspection: The entire insulation system was visually inspected for uniform cell outlines in the facing sheet, damaged cell nodes, and discolored facing sheets which may have resulted from temperature extremes encountered during the cure cycle. All identified suspect areas were subjected to a localized vacuum bell check at a vacuum of 20 inches Hg for one minute. All discrepancies were repaired prior to system pressurization.

2. Leak Check: The insulation system was pressurized to 3 psig and leak-checked using the bubble fluid technique.

3. Flow and Proof Pressure Test: The system was then pressurized to 7 psig in accordance with the time/pressure sequences noted in Figure 6.1.1.7-1. Purge gas flow was verified to be within engineering requirements. If excessive leakage was detected, the pressure was dropped to 3 psig and the leak check repeated.

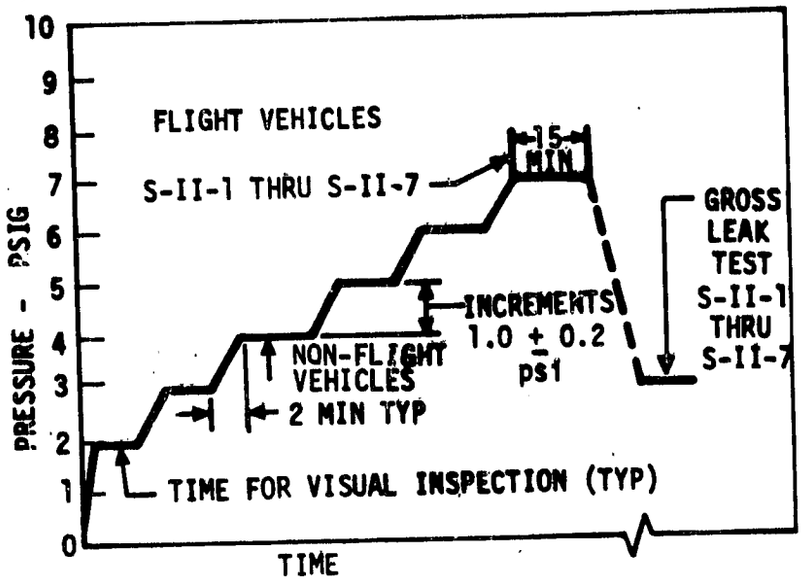
4. Final Visual: When all leak, flow, and proof pressure requirements were met and while the insulation system was pressurized, a visual inspection for the following was performed:

(a) Appearance of bubbles or blisters on the outer skin greater than 0.75 inch along the major dimension.

(b) Loss in skin-to-skin honeycomb bond over two cells.

(c) Appearance of raised areas greater than 2.5 inches in diameter (or three cell widths) that indicate core-to-aluminum voids.

If none of the above conditions was noted, the insulation system was accepted by Quality Assurance.



NOTE: ALL TIMES ARE MINIMUM

Figure 6.1.1.7-1. Pressure Schedule

6.1.1.8 Repair and Maintenance

a Repair: All repairs require Material Review Board approval.

1. Repair procedures (MA0606-040): The specification gives the repair procedure for gas barrier film, laminated face sheet, and honeycomb core. The part or assembly is restored to the design and structural intent of the insulation system.

2. Emergency Repair (MA0606-049): This specification establishes emergency repair procedures for use at Kennedy Space Center when the vehicle is on the launch pad. These repairs are not intended as permanent repairs and are used only when time does not allow use of the regular procedures.

b. Maintenance: No special maintenance is required.

6.1.1.9 Reliability

Two failure modes were identified: leakage and insulation separation. Results are presented in Table 6.1.1.9-1.

Table 6.1.1.9-1. FMEA-Honeycomb, Foam Filled, Helium Purged

Subsystem or Component	Failure Mode	Mission Effects - Remarks
Forward Bulkhead Hot-Bonded Insulation	Leakage of Helium Purge Gas through Rupture in Laminate	No redline for this circuit. Decrease or loss of purge gas would permit cryopumping of GN_2 used to purge the S-II/S-IVB interstage. Cryopumped GN_2 poses no structural problems. Should detanking be required, the rapid volatilization of LN_2 may damage the insulation, but no hazard would result. (NR Report SD-IL-67/152)
LH_2 Tank Side-Wall Insulation, Hot-Bonded	Leakage of Helium Purge Gas	Possible mission scrub. Requires increased topping rate of LH_2. Loss of helium purge. Possible formation of liquid air in LOX-sensitive insulation. Increased boiloff and possible shortening of mission.
	Debonds from LH_2 Tank	Possible mission abort. Increased boiloff resulting in possibly exceeding vent valve capacity and excess tank pressure.
Cold-Bonded Closeout Insulation	Tears Away From LH_2 Tank	Possible mission abort. Increased boiloff. Possible formation of liquid air in LOX-sensitive insulation.

6.1.1.10 Safety

a. Fabrication and Installation: During the fabrication and installation of parts and components of this insulation system the operations are conducted in accordance with the applicable sections of Industrial Safety Operations Standards, Pub 543-G-36, Rev. 11-68. Emphasis should be placed on Section VII, Industrial Operations, in this manual.

Toxic, caustic, and flammable materials are used and these operations should be performed by individuals who are trained in their proper use and who carry a valid certification of this training.

Flammable dust and debris result from the fabrication and installation of honeycomb insulation. To minimize the fire hazard and to prevent contamination of working surfaces housekeeping and area cleanliness should receive concentrated attention.

Care is used during the installation of component parts of this system to insure that no damage is done to components that have been installed.

b. Honeycomb Insulation Uses: The functional testing of honeycomb insulation systems will include a proof-pressure test of 125 percent of the maximum operating pressure.

The applied honeycomb is relatively fragile and damage is easily incurred after installation. When the exterior surface is struck by heavy objects the facing sheet can be delaminated and lead to further delamination by the "zipper" effect when the sidewall is pressurized. Care should be exercised in the use of honeycomb to insure that no damage to the insulation surface is sustained.

The helium purge gas should be verified to be free of contamination prior to use. When used to insulate hydrogen tanks 2 percent oxygen in the purge gas could combine with leaking hydrogen to form an explosive mixture. Contamination of any gas with the helium would condense on tank surfaces and solidify and block purge passages or provide a pressurizing source that could separate the insulation from the tank when the solidified gases warmed up and vaporized.

The purge gas should be introduced into the cavities in quantities sufficient to insure that negative pressure does not develop in the honeycomb. When the sidewall is exposed to cryogenic temperatures the purge gas will contract. A positive pressure within the honeycomb is necessary to insure that minute cracks or openings that are otherwise acceptable will not allow condensable gases to be forced into the purge channels by atmospheric pressure.

The chilldown rate and propellant fill rate of the tank should be carefully controlled to prevent the contraction of the tank wall from introducing stresses at the bond line that will separate the honeycomb from the tank wall.

After each cryogenic exposure the exterior surface of the honeycomb insulation should be inspected for damage. Any damage should be repaired and tested prior to another cryogenic exposure.

6.1.1.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 17 hours per square foot.

b. Schedule: The total schedule covering an insulation system will include procurement time, subassembly time, installation time, and checkout time:

Procurement time - 14 weeks.

Subassembly time - 6 weeks.

Installation time = 15 weeks.

Checkout time = 1 week.

c. Weight: The total as-installed weight of the 1.6-inch-thick insulation system is 0.8971 lb/ft^2. The outer laminate is 0.0546 lb/ft^2. The honeycomb core/foam for 1.6-inch-thick is 0.5853 lb/ft^2. The adhesive weight is 0.2400 lb/ft^2. The outer Tedlar seal is 0.0172 lb/ft^2.

d. Performance: The thermal performance (Q) of this insulation system is 250 Btu $hr\text{-}ft^2$. The ρK of the system is 0.447, where ρ is density in units of lb/ft^3, K is conductivity in units of $Btu/hr\text{-}^oF\text{-}ft$. ρK is a rating factor in units of $lb\text{-}Btu/hr\text{-}^oF\text{-}ft^4$.

6.1.2 Honeycomb, Evacuated, No Filler, Bonded

6.1.2.1 Description

A unique application of the honeycomb sandwich structure exists on the common bulkhead of the S-II Stage. An overall view of the structure is shown in Figure 6.1.2.1-1; assembly details are given in engineering drawings V7-313102 and V7-313106.

The primary function of the common bulkhead is to provide structural isolation between the LOX and LH_2 tanks. In addition, the common bulkhead performs as an insulator between the two cryogens. The insulating quality is attained through the helium-filled honeycomb core. Improved thermal efficiency is achieved by evacuation of the bulkhead prior to launch.

The common bulkhead is a bonded sandwich assembly employing aluminum facing sheets and fiberglass-phenolic honeycomb core. The core cell walls are perforated to perform three functions:

a. Permit ready distribution of the helium purge gas over the entire internal volume of the common bulkhead.

b. Provide evacuation path for the common bulkhead during cryogenic operations.

c. Provide leak-check capability of either facing sheet. Schematic of the purge and leak detection circuit is shown in Figure 6.1.2.1-2.

6.1.2.2 Application

a. Utilization: This system is applicable for minimizing heat leak in areas where structural geometry is the primary design factor. Optimum design of a launch vehicle requires that the weight of the primary structure be minimized with respect to the weight of the propellants required for the mission. The configuration of the individual fuel and oxidizer tanks and their arrangement within the overall vehicle must be structurally optimized if minimum weight is to be achieved. On the S-II stage this was realized by nesting the two tanks so that a single shell or bulkhead can be shared between them. This common bulkhead eliminates the weight of one

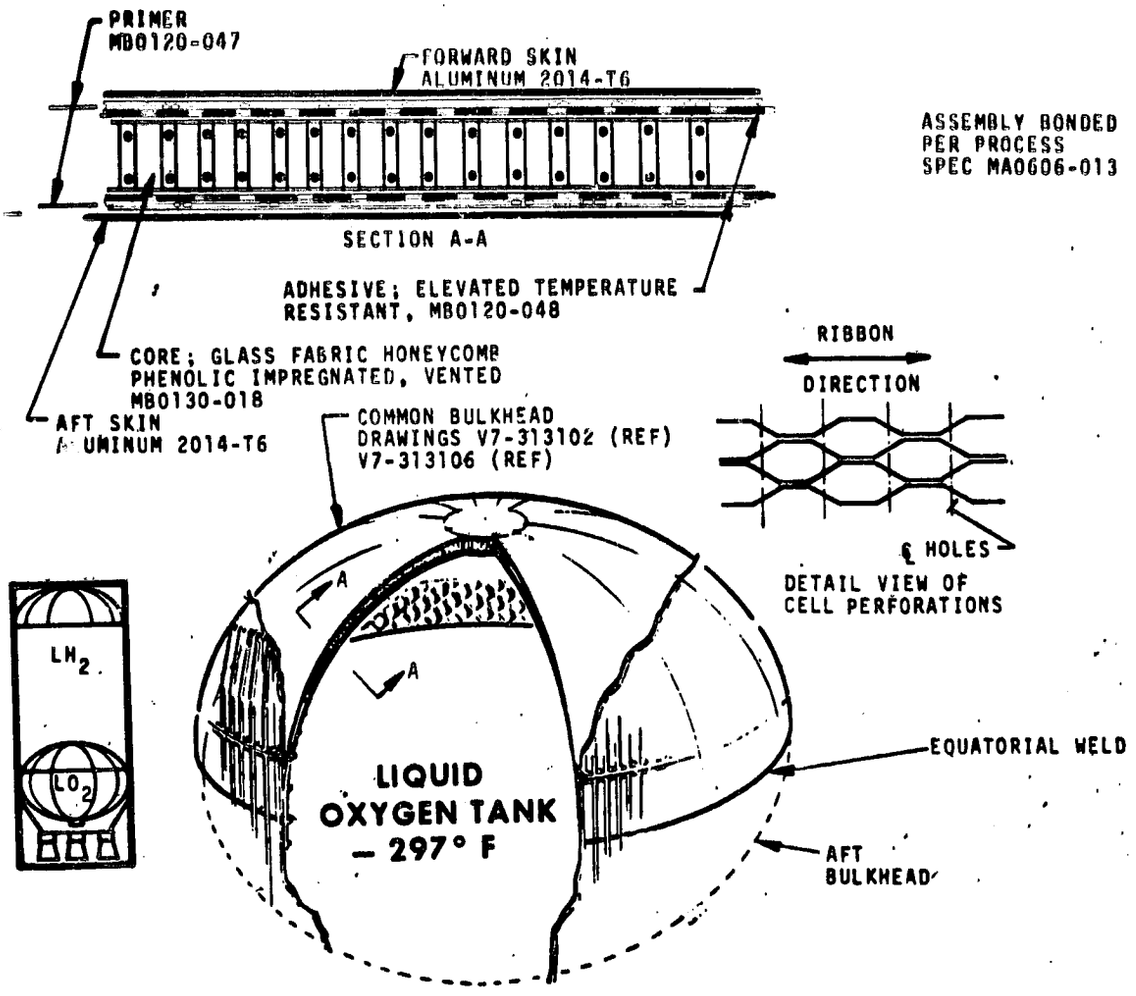


Figure 6.1.2.1-1. Honeycomb Base System Evacuated, No Filler, Bonded

bulkhead plus the intertank structure. Generally, it is necessary that the bulkhead be a composite structure if maximum strength and minimum weight is to result. On the S-II stage, this design provided a weight-saving of approximately 10,000 pounds and 230 inches in stage length over a separate-tank configuration (SID 66-44).

Where the bulkhead separates cryogenic propellants such as LH_2 and LOX, however, there is the additional problem of thermal isolation. It is necessary, therefore, that the core be made of non-conducting materials and that it be designed for minimum complexity in production.

The walls between adjacent cells are perforated and by proper arrangement of segments and bond lines, any desired purge gas path can be established.

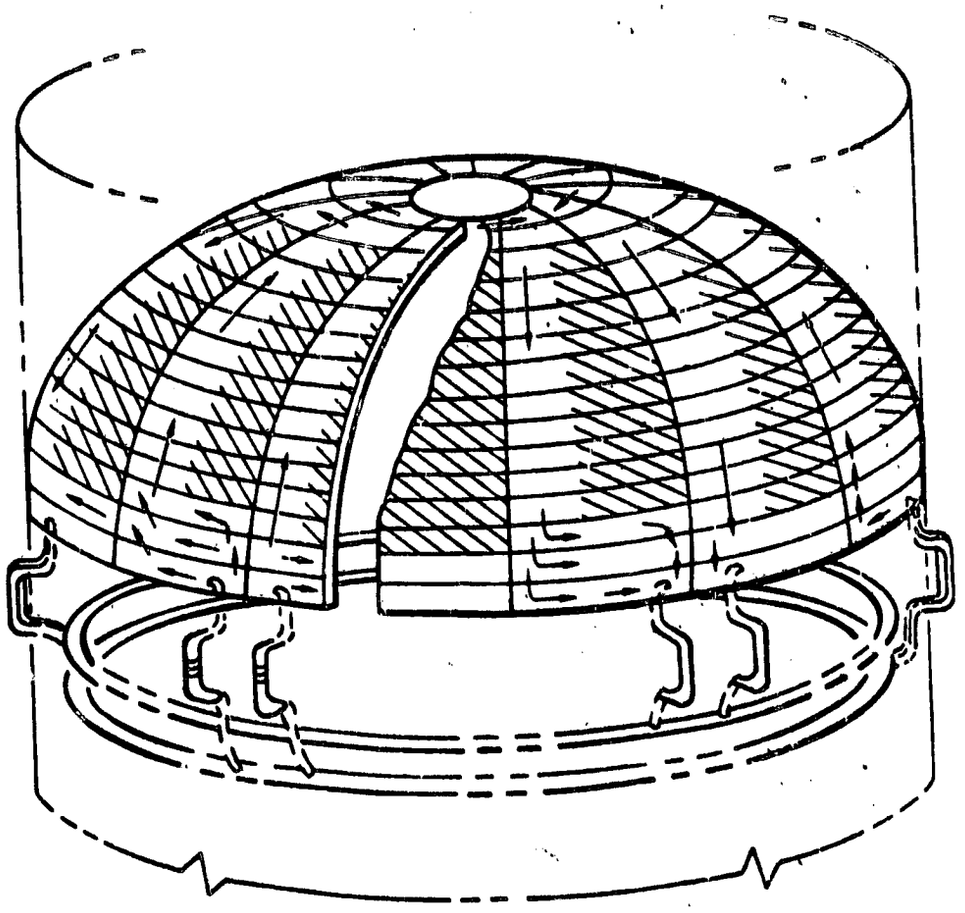


Figure 6.1.2.1-2. Schematic of Common Bulkhead Purge and Leak Detection Circuit

Figure 6.1.2.1-2 shows a path selected to allow the major portion of purge gas to wash rapidly across critical weld areas before exiting for early leak detection analysis.

To minimize the heat loss from the LOX ullage gas across the bulkhead into the LH_2, the bulkhead was evacuated during cryogenic operations. Nominal pressure at liftoff is less than 0.1 psia (SD 69-98).

This system can be applied to ground storage systems or to land or sea transport systems where structural separation is a prime driver. It is not recommended for application where heat transfer is the primary driver; however, it can be used in conjunction with other high-performance insulation systems such as internal radiation barrier for dewars.

b. Performance Characteristics: This system was used successfully on all S-II flight stages and three test stages. Tests specifically to measure thermal performance of this system were not conducted. Heat leak of 1845 Btu was predicted during launch of the S-II stage (SID 66-138) and calculations from the first 11 flights indicate total heat loss was well below allowable.

c. System Limitations: This system was developed to meet S-II system requirements as described in Section 5.0. Primary limitations are dictated by structural integrity and it is, therefore, necessary to restrict introduction of LH_2 onto the forward skin until the proper temperature distribution across the bulkhead is realized as a result of chilling to LOX temperature on the aft skin. For the S-II, it is required that the temperature at the lower edge of the forward skin be -160 F with 75 percent LOX load before LH_2 can be admitted (SID 66-1465-7).

d. Design Problems: Large areas of adhesive must be laid up within the time allowable for film adhesive to remain at room temperature. Work must be carefully preplanned and practices run to insure adequate time for contingencies.

It is also important that proper tests be conducted to insure no permeation through either the forward or aft skin prior to the start of bonding operations and a check must be made following final assembly.

Tests also must be conducted to insure proper distribution of purge gas prior to bonding the forward skin.

Each bulkhead skin experiences a degree of buckling near weld lands which must be taken into account in fitting mating honeycomb core. This requires careful measuring of contours which is converted to machining data by computer.

e. Design Verification Tests: Tests were conducted to verify structural adequacy of the common bulkhead. A total of 100 limit pressure cycles were applied in the burst direction and 5 cycles in the collapse direction (SID 66-44).

Tests have been conducted to measure the leakage into the common bulkhead on 15 flight stages and all have been within acceptable limits.

6.1.2.3 Thermal Performance

The thermal performance characteristics of this design are given for a common bulkhead between the LOX and LH_2 tanks. The analysis is restricted to predicting the heat transfer rate and accumulated heat transfer from LOX to LH_2 for the mission profile defined in Paragraph 4.2.2.3. The significant driver for insulation design is chilldown of the GOX ullage in the LOX tank.

The effective thermal conductivity of this insulation system as a function of residual helium gas pressure in the bulkhead is presented in Figure 6.1.2.3-1. The theoretical derivation and experimental verification of this curve is presented in Section 7.4. For the S-II application, the insulation was

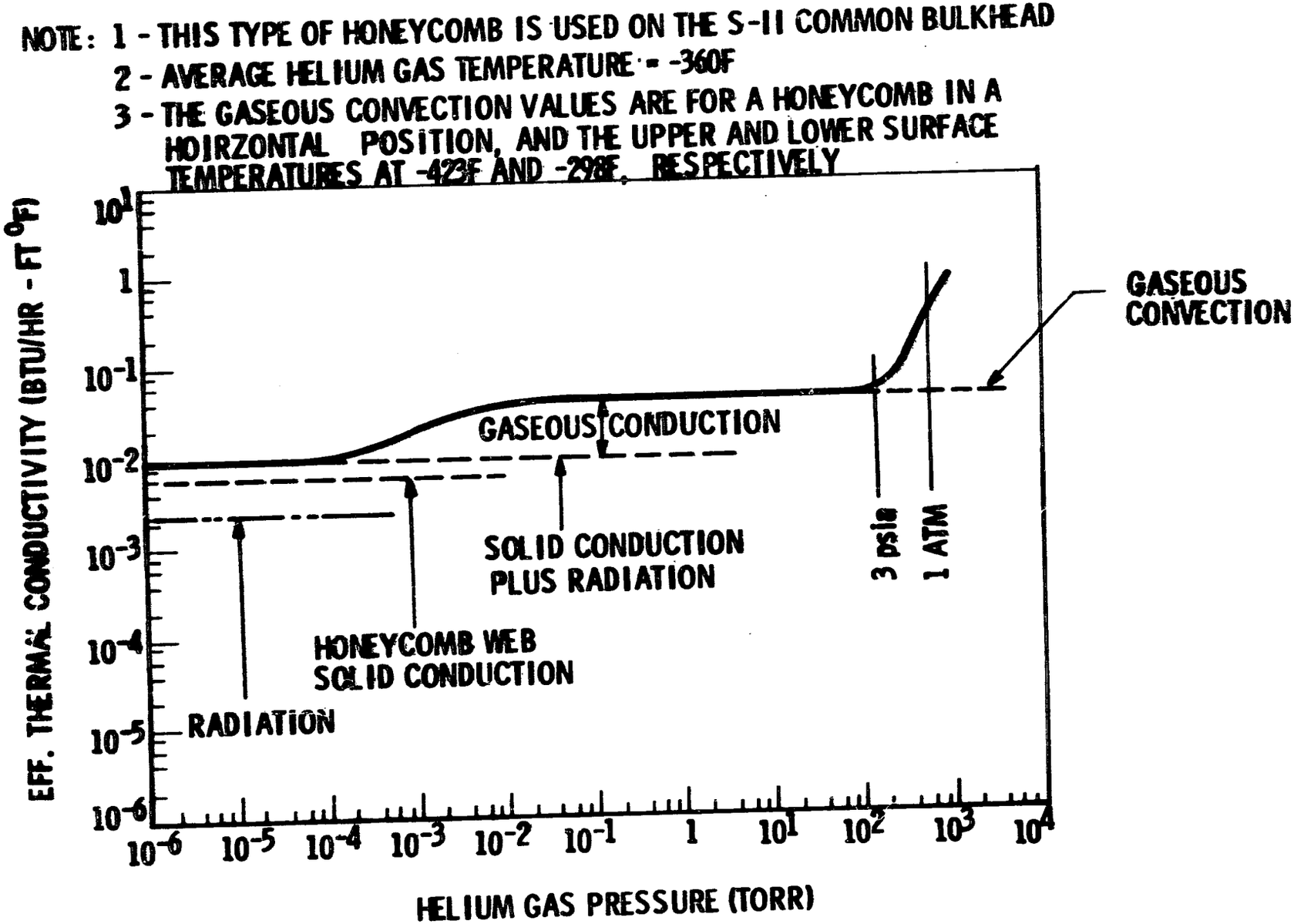


Figure 6.1.2.3-1. Effective Thermal Conductivity of 3/16-Inch Cell, 4.75-Inch Thick Phenolic Fiberglass Honeycomb Versus Helium Gas Pressure

Space Division
North American Rockwell

evacuated to approximately 3 psia. The corresponding K value is 0.04 Btu/hr, F-ft. and the predicted heat transfer rate is 12.7 Btu/hr-ft^2. The heat transfer to LH_2 across the insulated portion of the common bulkhead is 14,650 Btu during the S-II mission. This is approximately 7 percent of the LH_2 tank total. For the INT-21 and other S-II applications, further evacuation of the insulation is recommended to lower the effective thermal conductivity and resulting heat transfer. For example, a reduction in pressure to 10^{-4} Torr reduces the equivalent LH_2 boiloff rate from 63 to 15 lb/hr.

6.1.2.4 Structural Performance

In addition to functioning as an insulation system between the LH_2 and LOX tanks, the perforated honeycomb core also functions as a primary load-carrying structure of the common bulkhead.

The honeycomb sandwich has three discrete elements: the two face sheets and a honeycomb core. The core, in addition to stabilizing the face sheets, carries all the shear loads normal to the plane of the sandwich and direct tension or compression loads normal to the sandwich. The S-II common bulkhead was subjected to a wide range of pressure loadings (both collapse and burst conditions) and temperature gradients. To support structural analysis of the common bulkhead, a sophisticated analysis method and computer program was developed.

The important structural considerations in the selection of the honeycomb core were:

a. The core had to be thick enough and have sufficient shear rigidity and strength so that overall sandwich buckling, excessive deflection, and shear failure would not occur under design loads.

b. The core had to have high enough modulus of elasticity and the sandwich had to have great enough flatwise tensile and compressive strength so that wrinkling of either facing would not occur under the design loads.

c. The core cell spacing had to be small enough to prevent dimpling of the facings under design load.

6.1.2.5 Material and Processes

a. Materials:

1. Honeycomb: A vented glass fabric honeycomb core, impregnated with heat-resistant phenolic resin, 3/16-inch cell size and 4.0-lb/ft^3 density (MB0130-018).

2. Fabric: Reinforcing glass fabric (MB0135-009).

3. Primer: Solvent-carrying epoxy primer (MB0120-047).

4. Adhesives:

(a) Modified epoxy adhesive paste; not to be used for honeycomb sandwich face-to-core bond (MB0120-034).

(b) Foaming-tape adhesive system (MB0120-014).

(c) Thixotropic paste adhesive system (MB0120-026).

(d) Epoxy-phenolic glass fabric supported tape adhesive (MB0120-048).

b. Process: Material used for fabrication and installation were stored, handled, and processed in accordance with Section 11.0. The sequence of Bonding Operations for Common Bulkhead (MA0606-013) is as follows:

1. Subassembly Core Splicing: The bonding tool is used for fabrication of the segments (V7-313128) of honeycomb core (MB0130-018). The splice joints of the core in forming the segments are trimmed net or slightly oversize. To prevent rolling the edges at the splice joints during the bonding cycle, the maximum mismatch allowed is 0.080 inch. For mismatches above the allowable, one ply of adhesive (MB0120-048) is applied for each 0.020 inch above the allowable.

In areas of purge barriers or core stability, a thixotropic paste (MB0120-026) is injected into the cells of the core until filled. To facilitate the injection the paste may be warmed to 120 F. The assembly is cured at a pressure sufficient to assure core alignment and continuity of the aft core surface. The recommended cure temperature is 300 F for one hour. To prevent excessive warpage the pressure is maintained until cooled to 120 F. Upon completion of cure, all voids are filled with a modified epoxy adhesive (MB0120-034) and cured for 12 hours at room temperature.

2. First Stage Bonding Prefit: The 12 segments are assembled in the bonding fixture with a sheet of 0.016-inch polyvinyl chloride film between the segments and the aluminum aft face sheet. It is desirable to have a slight interference at the joint of the segments when assembled. The mismatch at the outer joint is faired by hand sanding to a maximum mismatch of 0.025 inch. Pressure is applied to the assembly and placed in the autoclave for an impression check to the

film. The assembly is subjected to a temperature of 200 F for a minimum of 10 minutes. The assembly is allowed to cool to 120 F or less before the pressure is removed. The segments are removed and the vinyl film is checked for core impression. Core areas which are filled with adhesive or paste will not produce an impression. These areas are identified so additional adhesive is not applied during the bonding. In the other areas, additional layers of adhesive are applied for subsequent bonding operation.

3. Primer Application to Aft Face Sheet: The surface of the metal structure is sprayed with a primer (MB0120-047) to an air-dry thickness of 0.5 to 1 mil. The primed structure is air-dried a minimum of 30 minutes between applied coats. This is to permit evaporation of the solvents from the primer. The primer is cured for one hour at 150 F.

4. Honeycomb Core Installation: Core segments are assembled on the adhesive in the same location with respect to the aft skin as during prefit.

5. First Stage Bonding: A vacuum of 20 inches of mercury is applied during transportation from the assembly area to the autoclave to prevent movement of the positioned honeycomb segments. After the assembly is placed in the autoclave a total pressure (vacuum plus augment) of 30 psi is maintained throughout the cure cycle. The temperature is raised from ambient to 230 F, restricting the temperature variation to 40 F between the hottest and coldest thermocouple and 20 F between adjacent thermocouples. The temperature is held at 240 F until the variation of 10 F is held among all thermocouples. Maintaining 10 F variation among thermocouples, the temperature is increased to 260 F and held for 12 hours, then cooled to 120 F. Any time the aluminum face sheets are subjected to elevated temperatures the variation of temperature among thermocouples is monitored. The variation of temperatures was determined by test to prevent distortion of the assembly.

6. Machining of Outer Surface of Core: The outer surface of the core is machined to dimensions derived from measurements of the concave surface of the forward face sheet.

7. Prefit Forward Face Sheet: This procedure is the same as that described in Item 2.

8. Primer Application Forward Face Sheet: This procedure is the same as that described in Item 3.

9. Second Stage Bonding: This procedure is the same as that described in Item 5.

6.1.2.6 Manufacturing

a. General Description: The common bulkhead was difficult to fabricate because of its size (33 feet in diameter) and spherical shape. The forward and aft face sheets of the sandwich were complete sheet metal

bulkheads that had to be measured accurately in more than 8,000 places. These data were later reduced by computer to machining data for the machining of the tapered core. The core was tapered from 4.5 inches at the apex to less than 0.2 inch at the lower skirt. The accuracy of the mold line match was required to stay within 0.010 inch, the tolerance of the adhesive film thickness. This matching tolerance was verified through several vinyl film impression checks which simulated the adhesive film and the total layup and autoclave procedures, all of which was very time-consuming and yet necessary to assure a void-free assembly.

All of the phenolic honeycomb core was purchased in the pre-contoured shape and in segments approximately 4 feet square. These squares were prefit and edge-bonded to make larger gore-segmented subassemblies which were later bonded directly to the aft bulkhead facing sheet. The many bonding sequences for this insulation system are shown in Figure 6.1.2.6-1.

It should be noted that if this insulation concept were used on flat or cylindrical assemblies the manufacturing considerations would be considerably simpler.

b. Tooling and Equipment: The primary tools required for the S-II common bulkhead were:

1. Compound contoured core layup and bonding tools.

2. Compound contoured core edge trim tool with diamond dust cutting wheel.

3. A large (33-foot diameter) bulkhead bonding fixture.

4. A large (33-foot diameter) tailored vacuum bag for bonding pressures.

5. A (33-foot diameter) bulkhead tracing and measuring fixture.

6 A (33-foot diameter) vacuum bell handling fixture for the aft bulkhead skin.

7. A bulkhead turnover fixture required for the chemical cleaning and priming operations.

The principal equipment used for the bulkhead operations consisted of:

1. A large (15- by 12- by 30-foot) curing oven for core bonding.

2. A 36-foot-diameter clamshell autoclave for the high-pressure bonding operations and primer curing.

3. Spray chemical cleaning facilities sized to clean the forward and aft facing sheet bulkhead prior to primer application.

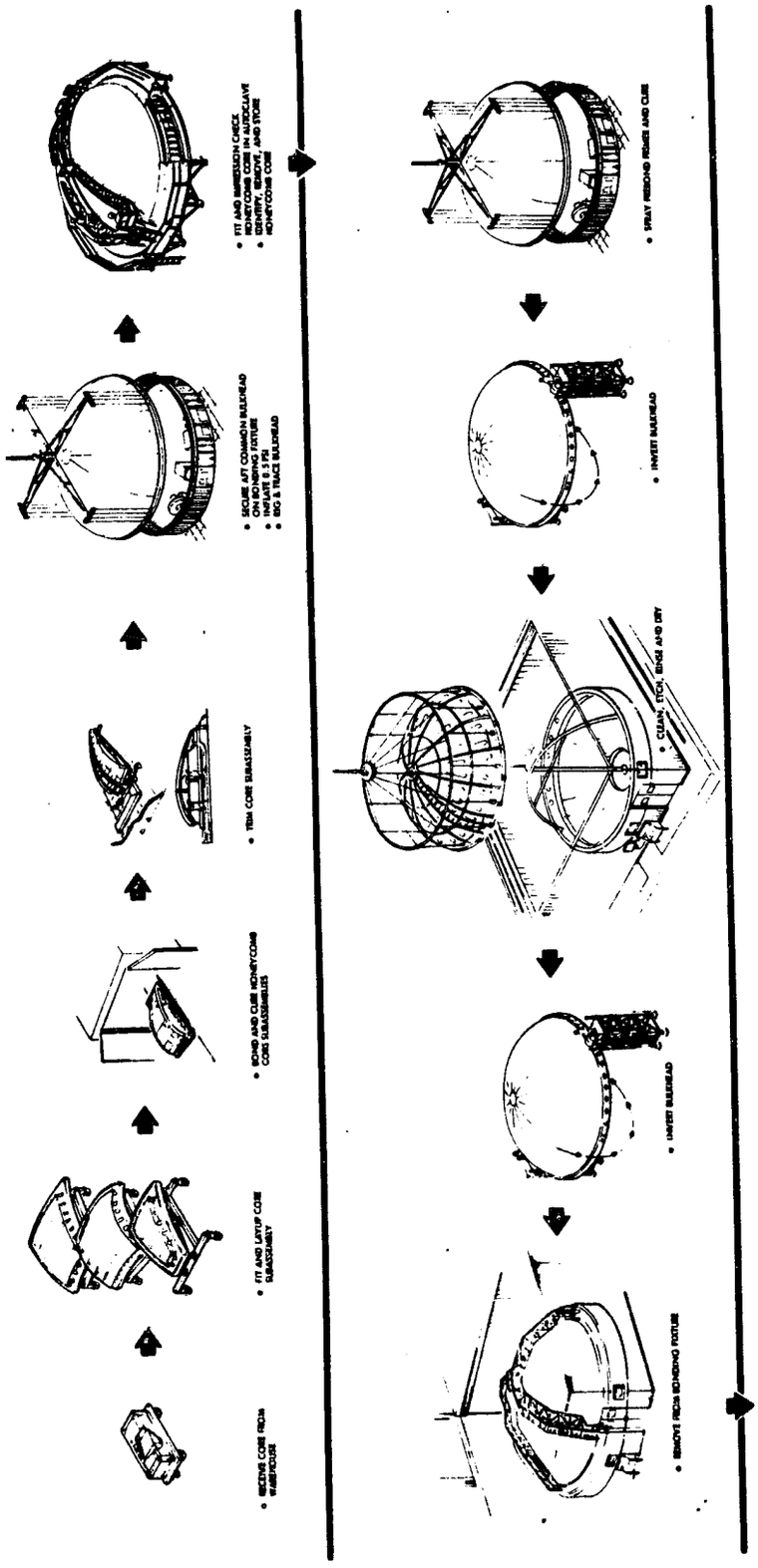


Figure 6.1.2,6-1. Common Bulkhead Bonding Sequence (Sheet 1 of 2)

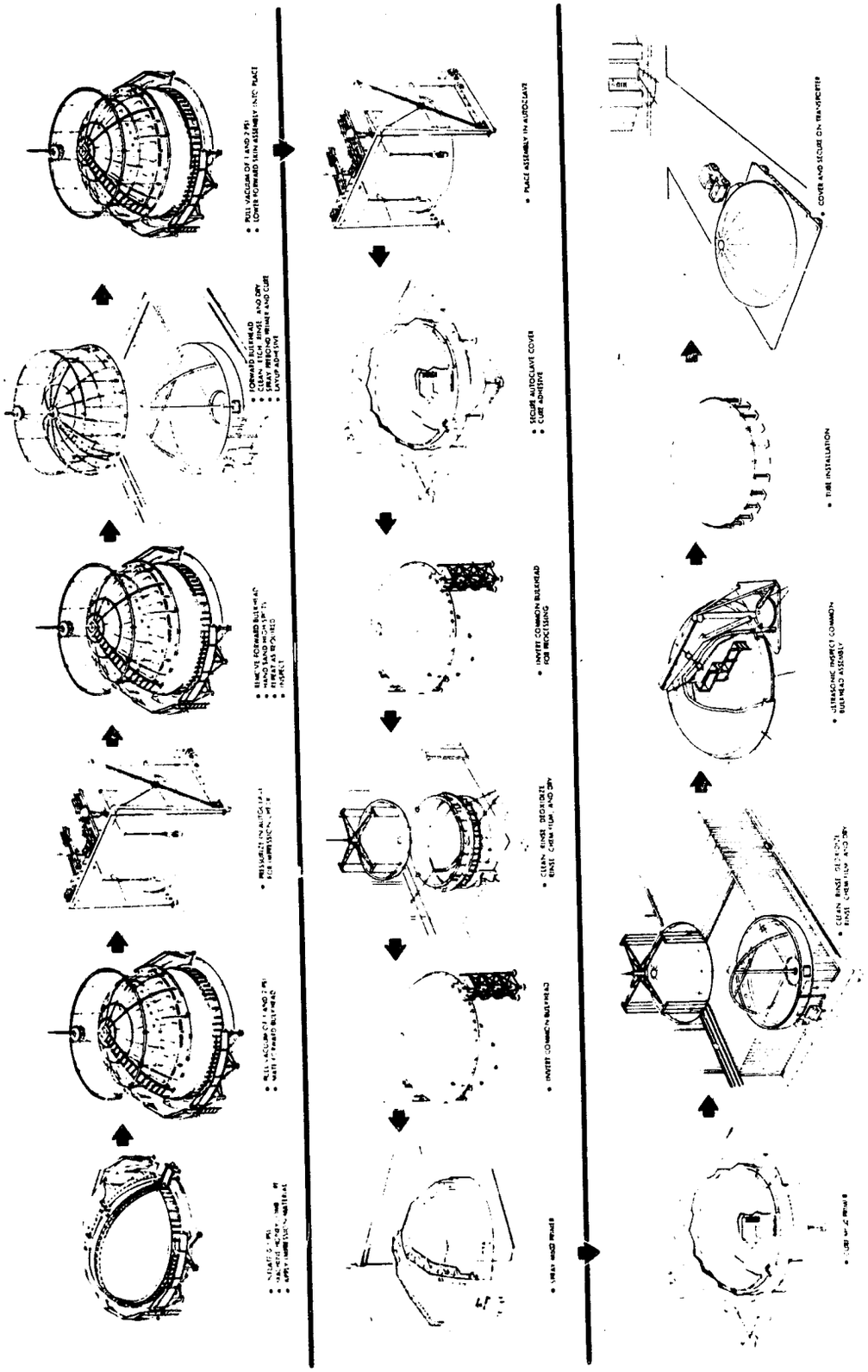


Figure 6.1.2.6-1. Common Bulkhead Bonding Sequence (Sheet 2 of 2)

6.1.2.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0606-013).

1. Core Detail Subassembly Inspection: The entire HRP honeycomb core system employed in the common bulkhead was fabricated from small details laid up on tooling contoured to match the configuration of the aft facing sheet. Each detail was inspected for proper edge dimension and core splice mismatch.

2. First Stage Bond Prefit: The core details were assembled on the aft facing sheet using a 0.016-inch thick sheet of polyvinyl chloride (PVC) film between the core and the facing sheet. The assembly was vacuum bagged and installed in the autoclave. A total pressure (vacuum plus autoclave) of 15-18 psi at 200 F was then applied for a minimum of 10 minutes. A uniform impression of core on the PVC film was required prior to first stage bonding. Specific core impression requirements were established (MA0606-013).

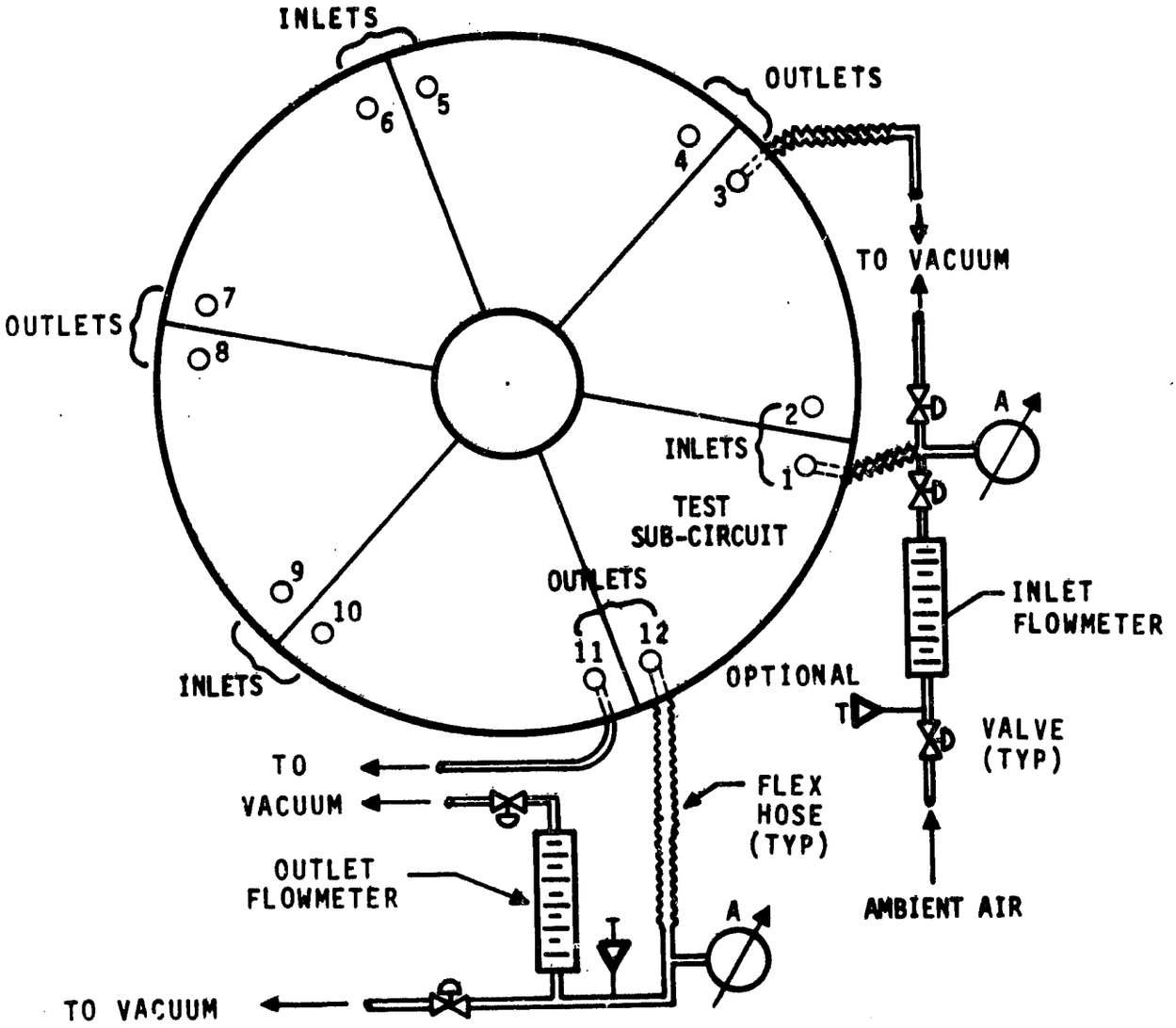
3. First Stage Bond: Routine controls (defined in Section 15.0 of this report) were invoked for cleaning of details, primer application, equipment integrity, and cure monitoring. One unique aspect of the bonding operation was that the total adhesive lay-up operation required considerable time while employing an adhesive system stored under refrigeration. The cumulative time between removal of the adhesive from refrigeration and final application of heat to the bonded assembly was monitored and controlled. As an added safeguard, all adhesive validation prior to fabrication of a common bulkhead was conducted employing maximum open assembly times allowed for the production bonding operations.

4. Evacuation Purge Flow Check (MA0201-1837): This flow check was performed just prior to the second stage bonding operations. A transparent plastic film was used to simulate the forward facing sheet. The objective was to verify that complete free flow through the honeycomb core was achieved uniformly through all sub-circuits. The basic setup is shown in Figure 6.1.2.7-1.

5. Second Stage Bond Pre-Fit: This pre-fit operation was conducted essentially the same as the first, except that the forward facing sheet was in place and the total pressure was 22-25 psi at 200 F.

6. Second Stage Bond: Quality control provisions were identical to the first stage bonding operations.

7. Process Verification Coupons: Process verification coupons were fabricated simultaneously with the production assembly. Where applicable,



NOTE: THIS FIGURE TO BE USED ONLY AS A GUIDE FOR THE TEST SET-UP

Figure 6.1.2.7-1. Vacuum Flow Test With Transparent Cover on Core

coupons represented the same surface preparation, storage, handling, open assembly time, and cure cycle as the production bond. The tests consisted of:

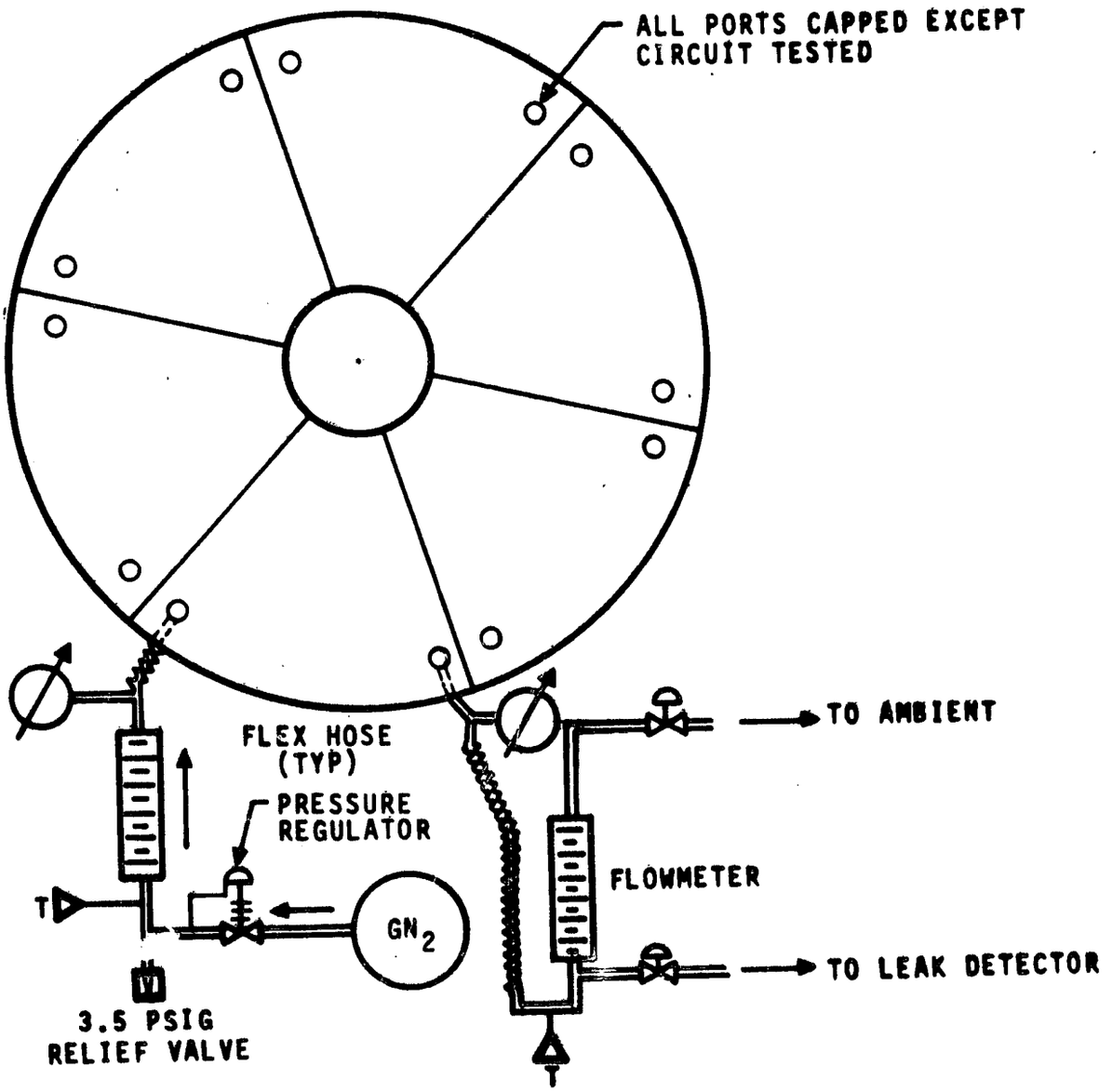
(a) Lap shear strength

(b) Honeycomb flatwise tensile strength

(c) Honeycomb peel strength

c. Quality Verification of Final Assembly:

1. Nitrogen Flow Check (MA0201-1837): Following the second stage bonding operation, a nitrogen gas supply was connected to each sub-circuit, as shown in Figure 6.1.2.7-2. At a supply gas pressure of 3 psig, the stabilized flow through each sub-circuit was verified to be at least 2 scfm.



NOTE: THIS FIGURE TO BE USED ONLY AS A GUIDE FOR THE TEST SET-UP

Figure 6.1.2.7-2. Pressure Flow Test After Forward Tank Structure Bonded

2. Vacuum Decay Test (MA0201-1837): As a final inspection of the seal integrity of the bonded assembly, a vacuum decay test was performed. The test setup was as shown in Figure 6.1.2.7-3. The assembly was pumped down to 100 mm of Hg, pump source shut off, and vacuum decay rate measured. A maximum decay rate of 130 mm of Hg/hour was allowed.

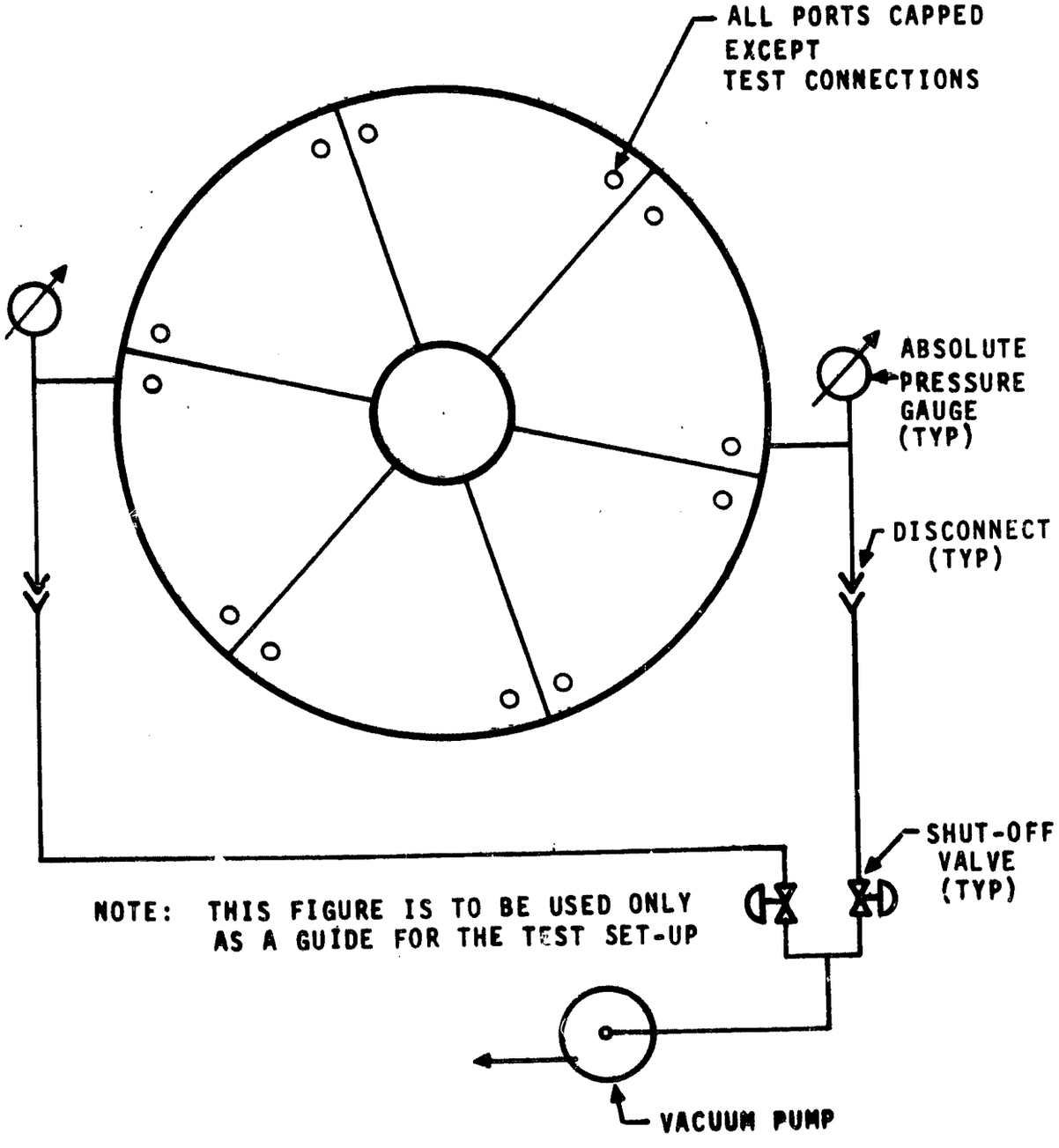


Figure 6.1.2.7-3. Vacuum Decay Test

3. Ultrasonic Inspection: Ultrasonic inspection (MQ0501-010) was performed prior to final Quality Assurance acceptance of the completed assembly. All potential leak paths were masked and sealed with a chloroprene-type strippable sealer to prevent entrance of the water couplant employed in the inspection. A 100-percent C-scan recording was made of the entire assembly.

6.1.2.8 Repair and Maintenance

The common bulkhead insulation system was part of the structure of the stage; because of the structural requirements, no in-process repairs were written. All discrepancies to the bulkhead required full Material Review Board approval.

6.1.2.9 Reliability

Three major failure modes are identified: core collapse, skin rupture, and leakage. Results are presented in Table 6.1.2.9-1.

Table 6.1.2.9-1. FMEA—Honeycomb, Perforated, Evacuated

Subsystem or Component	Failure Mode	Mission Effects Remarks
Common Bulkhead	Core Collapse	Tanks exceed differential pressure capacity, bulkhead collapse, probable explosion
	Rupture Forward or Aft Skin	
	LH_2 Leak	Scrub launch, sufficient purge will reduce danger on pad. During flight - LH_2 boiloff increase, solid oxygen will form, possible bulkhead rupture and vehicle loss.
	LOX Leak	Scrub launch, sufficient purge will reduce danger on pad. During flight - fire hazard due to LOX sensitive phenolic core.

6.1.2.10 Safety

a. Fabrication and Installation: Safety requirements are the same as those described in Paragraph 6.1.1.10.

b. Insulation System Use: The honeycomb interior of the common bulkhead is not available for visual inspection. This fact places limitations on the utilization of this insulation system.

Care should be taken to insure that no contaminants are introduced into the honeycomb through purge or leak test lines. Once introduced, the contaminants would be difficult or impossible to remove and the insulating qualities would be reduced.

The large area of the common bulkhead makes it mandatory to conduct the preloading chilldown and leak tests to specification requirements. The transition from a warm bulkhead to LH_2 and LOX temperatures could introduce thermal stresses that could lead to rupture if the chilldown were too rapid. The leak test after chilldown is to verify that no cracks have developed.

6.1.2.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 12 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 12 weeks.

Subassembly - 4 weeks.

Installation - 6 weeks.

Checkout - 1 week.

c. Weight: The total as-installed weight is 1.653 lb/ft^2. The Type IV adhesive (MB0120-048) (2 sides) is 0.322 lb/ft^2. The core (MB0130-018) (4-inch thick) is 1.331 lb/ft^2.

d. Thermal Performance: The Q of this system is 40 $Btu/hr/ft^2$. The ρK of this system is 0.397 $Btu/lb/hr-{}^oF-ft^4$.

6.1.3 Helium-Purged, Foam-Filled, Honeycomb Panels Mechanically Attached Over Bonded Foam Blocks

6.1.3.1 Description

One of the more complex of the insulation systems used on the S-II stages is the one installed over the lower portion of the forward skirt. For installation illustration see Figure 6.1.3.1-1 (V7-532196).

Insulating qualities of this insulation system are obtained from the bonded foam blocks located between the stringers, and, for the most part, from the helium gas within the bolted-on honeycomb sandwich panels. This system performs during ground hold and boost phases. The bolted-on panels and the leading edge fairings are highly resistant to aerodynamic heating and erosion.

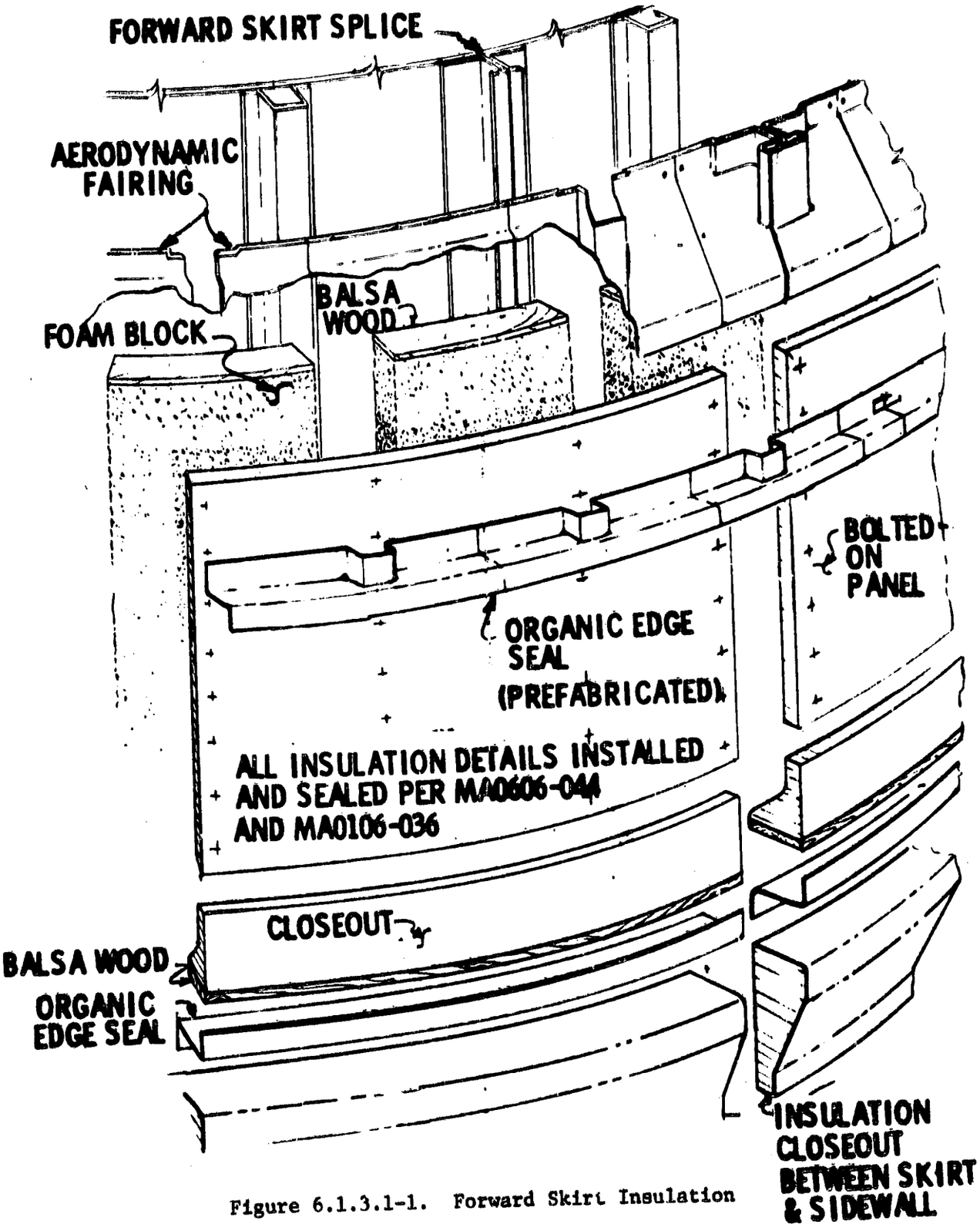


Figure 6.1.3.1-1. Forward Skirt Insulation

As shown in Figure 6.1.3.1-1, the complete installation consists of many details and subassemblies. The description and function of components is as follows:

a. Foam block – provides thermal protection.

b. Bolt-on panel – provides erosion-resistant surface and thermal insulation over stringers.

c. Organic edge seals – provide leak-tight border for insulated area.

d. Aerodynamic fairing – A bolted-on fiberglass laminate protects insulation leading edge.

6.1.3.2 Application

a. Utilization: This insulation system shown in Figure 6.1.3.1-1 is a method of providing thermal protection for areas of complex structural geometry. It was developed to the specific requirements of the S-II stage forward skirt area (Figure 6.1.3.2-1). It can be applied to other applications with similar complexities.

b. Performance Characteristics: This system was successfully used on S-II flight stages. Tests to measure thermal performance of this system were not conducted; however, heat leak during ground hold and launch was calculated as 2320 Btu total (SID 62-138).

c. System Limitation: This system was designed to meet the specific conditions related to the S-II forward skirt area and was qualified for temperatures up to 365 F. Service temperatures for any application should not exceed that value while in sensible atmosphere.

d. Design Problems: Problems related to material selection are the same as those for other systems. Certain specific problems related to this system are:

1. Manufacturing tolerances in the primary structure details present varying dimensions between stringers. This can result in varying bond lines or require filling or trimming for the insulation details during final manufacturing operations.

2. The deflections experienced by the skirt structure may require specific design consideration in the areas directly over the stringers.

3. Where helium purge is used, it is necessary that an edge seal be provided. For this system balsa wood can be used with an organic seal composed of nylon cloth and polyurethane adhesive. These closures must be designed so that all hidden bonds are available for inspection and check before final closeout.

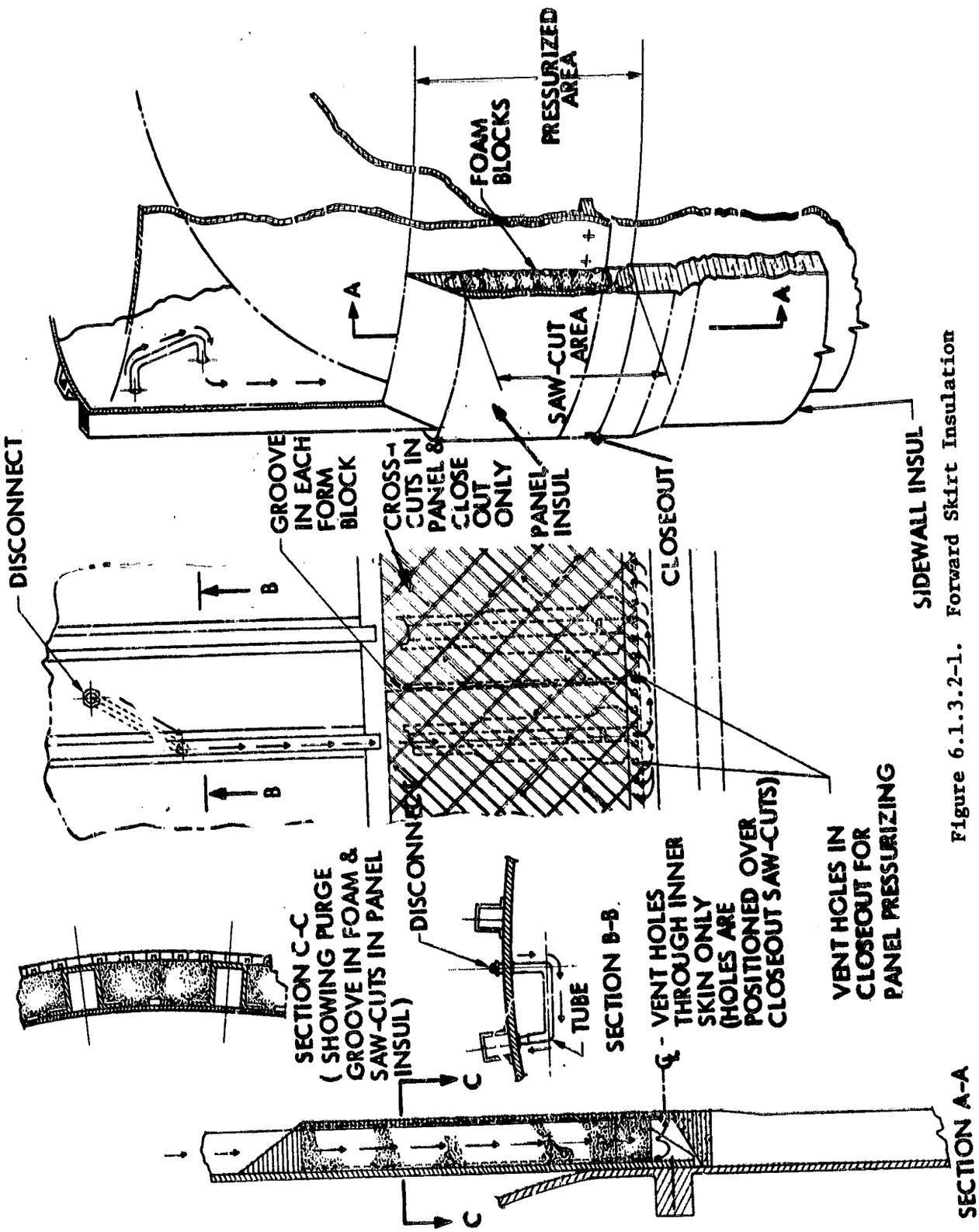


Figure 6.1.3.2-1. Forward Skirt Insulation

4. Complete sealing of the forward section was difficult to obtain because of the many details, splices, attach bolts, edge members, and irregular shapes (especially around the hot section stringers). All these areas had to be sealed by bonding process. This problem was reduced by careful adherence to the in-process controls. Verification of the manufacturing process was made through test coupons and laboratory testing.

e. Design Verification Tests: This system was qualified by similarity to the basic helium-purged insulation described in Paragraph 6.1.1.1. Tests were conducted on a configuration utilized on the bolting ring area of the S-II. In these tests, three specimens were tested under combined environment of vibration and simulated aeroheat and pressure while maintaining the test tank at LH_2 temperature. All tests were successful (Reference 24).

6.1.3.3 Thermal Performance

The thermal performance characteristics of helium-purged foam-filled honeycomb panels mechanically attached over bonded foam blocks are given for a launch vehicle tank containing LH_2 which is exposed to ground-hold and launch environments. These environments are defined in Paragraph 4.1.1.2 and Figure 4.2.2.3-1. The only supporting thermal analysis available assumes that this insulation is an extension of the basic sidewall insulation. Thus, the predicted operation will be the same. There are variations in heat transfer caused by the attachment methods; however, no special analysis was considered necessary. The bonded-in-place foam blocks filled up structural cavities or discontinuities in the surface. The external honeycomb with foam covered the ribs.

The helium-purged honeycomb was assumed to have the same rate of heat transfer as pure helium alone. This rate was such that the inside surface temperatures reached unacceptable values for their aluminum sections on the thermal design trajectory.

A considerable analysis effort was performed regarding application of this insulation system and is considered to be too voluminous for repetition in this report.

6.1.3.4 Structural Performance

The primary function of this insulation system is to provide thermal protection; it is not intended to be a primary load-carrying structure. However, as in the case of most insulation systems, this system, as used on the S-II stage, is required to match the deflections of the forward skirt and also is subjected to thermal gradients and pressure loadings. As a result, stresses and strains are introduced into the insulation.

Although the insulation system is of lightweight construction, it is not continuously bonded to the forward skirt. Hence, the effects upon stress levels of the dynamic response must be considered. As shown in Figure 6.1.3.1-1, the honeycomb panels were mechanically attached to the forward skirt stringers. These attachments were spaced sufficiently close that dynamic effects for this insulation system were considered negligible.

Of prime importance from a structural analysis standpoint are:

a. This insulation system utilizes organic materials which exhibit a visco-elastic behavior different from the normal elastic behavior of metals. The structural analysis of organic materials is discussed in Section 8.0.

b. The thickness of adhesive layers must be sufficient to insure proper bonding between the core and nylon facing sheets in order to sustain the core internal pressure loading. Local debonds propagate rapidly when subjected to differential pressure loading.

c. The significant stresses and strains are introduced into this insulation system as a result of differences in thermal contraction and expansion rates between the different materials, forward skirt deflections, and internal pressure within the insulation system.

6.1.3.5 Material and Processes

a. Materials:

1. Honeycomb: The core is non-vented, fabricated of glass fabric, impregnated with heat-resistant phenolic resin (MB0130-014).

2. Foams: Low-density (2.0 lb/ft^3), rigid, polyurethane open cell foam (MB0130-015).

3. Film: Polyvinyl fluoride material (MB0130-024).

4. Fabric:

(a) Glass fabric phenolic impregnated (MB0130-004).

(b) Woven nylon cloth (MB0135-021).

5. Primer: Modified polyester/isocyanate adhesive primer (MB0120-042).

6. Adhesive:

(a) Foaming-tape adhesive system (MB0120-014).

(b) Polyurethane resin system (MB0120-024).

(c) Thixotropic paste adhesive system (MB0120-026).

(d) Epoxy-phenolic glass fabric supported tape adhesive (MB0120-048).

(e) Contact adhesive (MIL-A-5092 Type I).

b. Processes: Materials used for fabrication and installation of the helium-purged, foam-filled, mechanically attached bonded block insulation system are stored, handled, and processed in accordance with Section 11.0.

1. Fabrication of Aerodynamic Fairing and Laminate Closeouts (MA0605-006): To prevent voids occurring between laminates (MB0130-004) during cure due to normal outgassing of the reaction product, the maximum thickness for a single stage cure is 0.125 inch. Where additional thickness is required, multiple stage cure is applied. In this type of cure each stage should consist of approximately the same number of laminates. Each stage is partially cured at 160 F for one hour with an applied vacuum of 26 inches of mercury. The stages are then combined and a complete cure is applied. The final cure requires increasing the temperature in 10 steps with an applied pressure of 50 to 100 psi depending on the total thickness being bonded.

2. Fabrication of Foam Blocks: The foam blocks (MB0130-015) are commercially purchased and machined to drawing configuration.

3. Fabrication of Organic Edge Seal (MA0105-049): See Paragraph 6.1.1.5.

4. Forward Skirt Installation (MA0606-044):

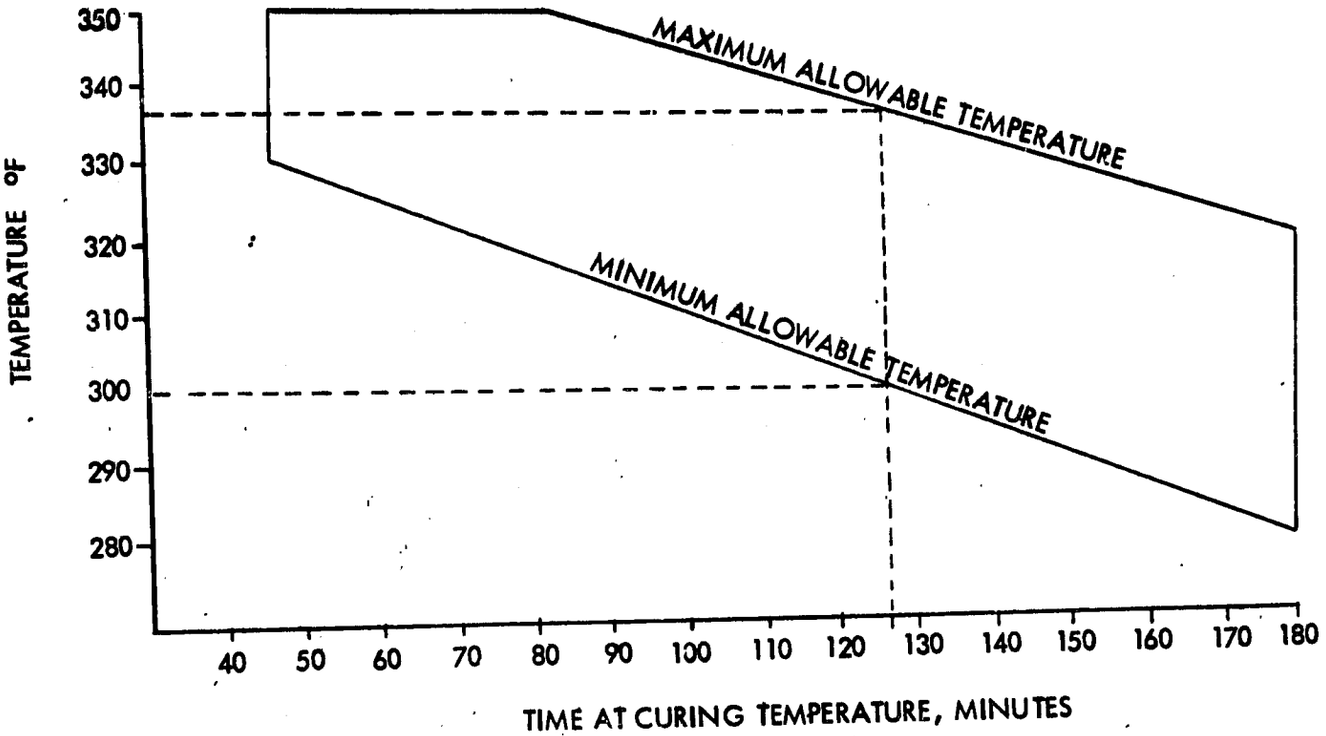
(a) Installation of Foam Blocks: A smooth coat of adhesive (MIL-A-5092 Type I) is applied to the foam blocks and the skirt structure and allowed to dry 5 to 30 minutes prior to assembly of the foam blocks.

(b) Sealing of Mechanical Fasteners: The honeycomb panels are mechanically attached to the external stringers of the forward skirt. The mechanical fasteners are solvent-cleaned with methyl ethyl ketone and dipped in adhesive (MB0120-024) prior to installation. The fastener attachments are further sealed by bonding adhesive-impregnated nylon fabric (MB0135-021) over the head of fasteners. The adhesive is cured 48 hours minimum at temperatures of 70 to 120 F prior to application of internal pressure.

(c) Bonding Vertical Closeouts: The closeouts are bonded over the joints of mating honeycomb panels with a heat cure adhesive (MB0120-048). Before bonding the closeouts, the area is wiped with methyl ethyl ketone. The cure of the adhesive is in accordance with Figure 6.1.3.5-1.

(d) Sealing Closeouts: The edges of the closeouts are sealed with strips of nylon fabric (MB0135-021) impregnated with polyurethane adhesive (MB0120-024).

(e) Bonding Preformed Edge Seal: To insure adhesion, the aluminum structure and insulation composite faying surfaces are primed. The balsa wood on the leading edge of the foam blocks is sealed with a brush coat of polyurethane adhesive. The adhesive is allowed to dry 16 hours at room temperature before any further



NOTES: (1) TIME TO CURING TEMPERATURE: 30 TO 120 MINUTES
(2) TIME TOLERANCE: + 15 MINUTES, -0

Figure 6.1.3.5-1. Adhesive Cure Requirements

processing. The details are assembled with an applied pressure of 2 to 10 psi. The polyurethane adhesive is cured in accordance with Table 6.1.3.5-1. After the cure is complete, two additional coats of adhesive (minimum of 12 hours between coats) are applied to the nylon fabric.

6.1.3.6 Manufacturing

a. General Description: Helium-purged, foam-filled honeycomb panels mechanically attached over bonded foam blocks was one of the more complex insulation systems because of the many detail parts of various configurations involved.

The solid foam blocks were trimmed at assembly and bonded in place between the skirt stringers. The bolt-on panels were prefabricated using the same manufacturing sequence described in Paragraph 6.1.1.6.

Table 6.1.3.5-1. Cure Cycle for MB0120-024

Cure Cycle Code	Time at Temperature
A*	12 hours minimum at 70 to 120 F plus 4 hours at 160 ± 10 F**
B	7 days at 70 F (minimum)***

*Cure A is a two (2) stage cure cycle

**The temperature shall be measured by thermocouples

***Pressure may be removed after twenty-four (24) hours.

The organic edge seals were prefabricated by making wet layups over the tool mold of the various configurations of forward and aft edges. Edge seals formed the pressure barrier of the forward skirt area which was isolated from the sidewall insulation.

The forward and aft closeout panels were prefabricated in the same manner as the side wall panels except they were thicker. The balsa wood edge members which separated the edge seals were precut to shape and bonded in place at the same time as the organic edge seals. All of the bonding was accomplished using room-temperature curing liquid and thixotropic paste adhesives.

The aerodynamic fairings were fabricated using pre-impregnated cloth laid up on specially configured bonding tools. The pressure and curing was accomplished using vacuum-bagging techniques and autoclave pressure and temperatures. The fairings were then trimmed and installed using mechanical fasteners. The leading edge was sealed with an elastic sealant applied with a pressure gun.

The basic manufacturing assembly sequences are shown in Figure 6.1.3.6-1.

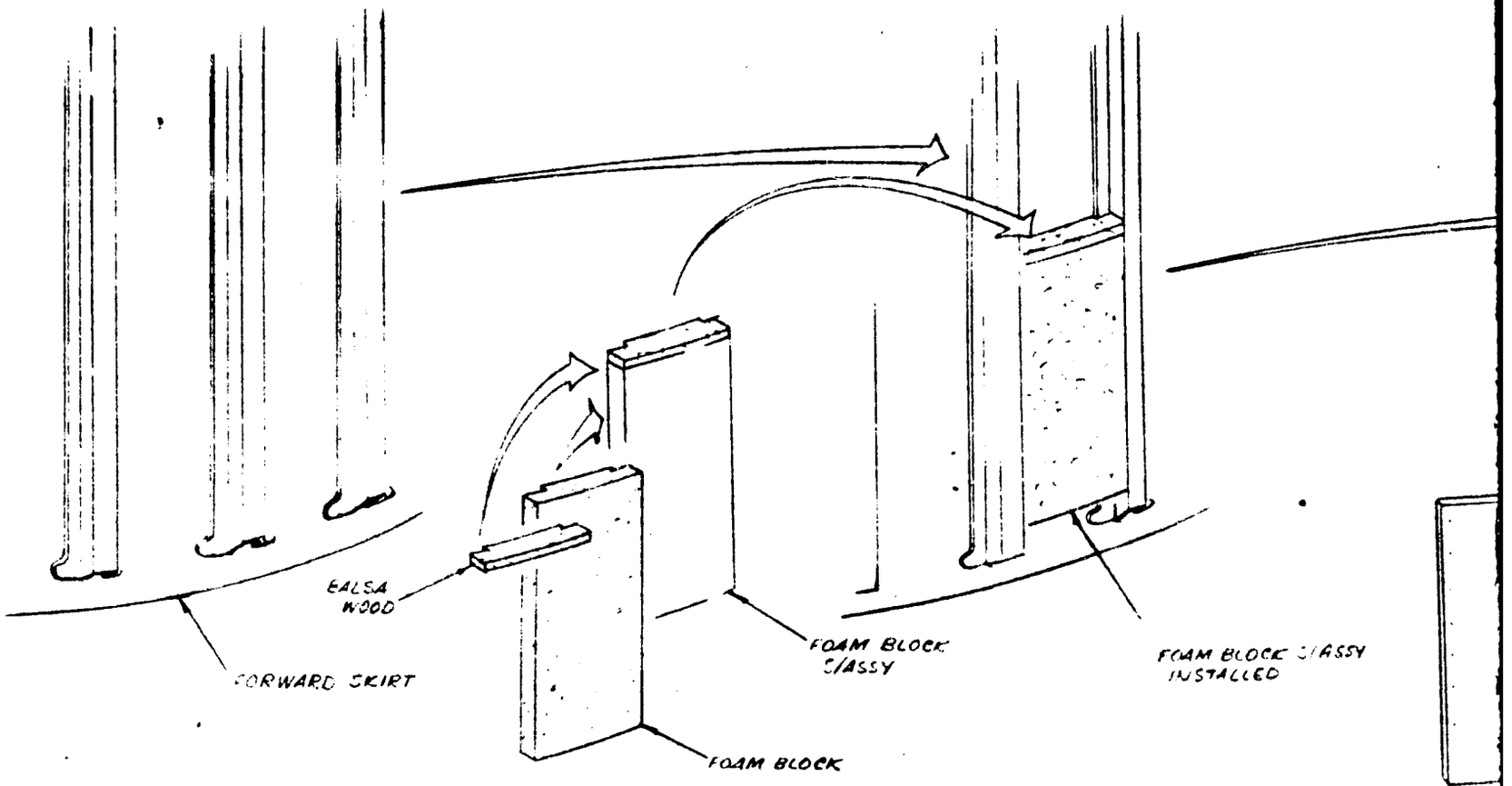
b. Tooling and Equipment: Tools used were templates, molds, and bonding tools. Equipment used were standard-sized autoclaves, ovens, and trimming saws.

6.1.3.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control:

1. Process Control: Process controls during detail fabrication and installation relative to the organic edge seals and insulation closeout sections were identical to those described in Paragraph 6.1.1.7.



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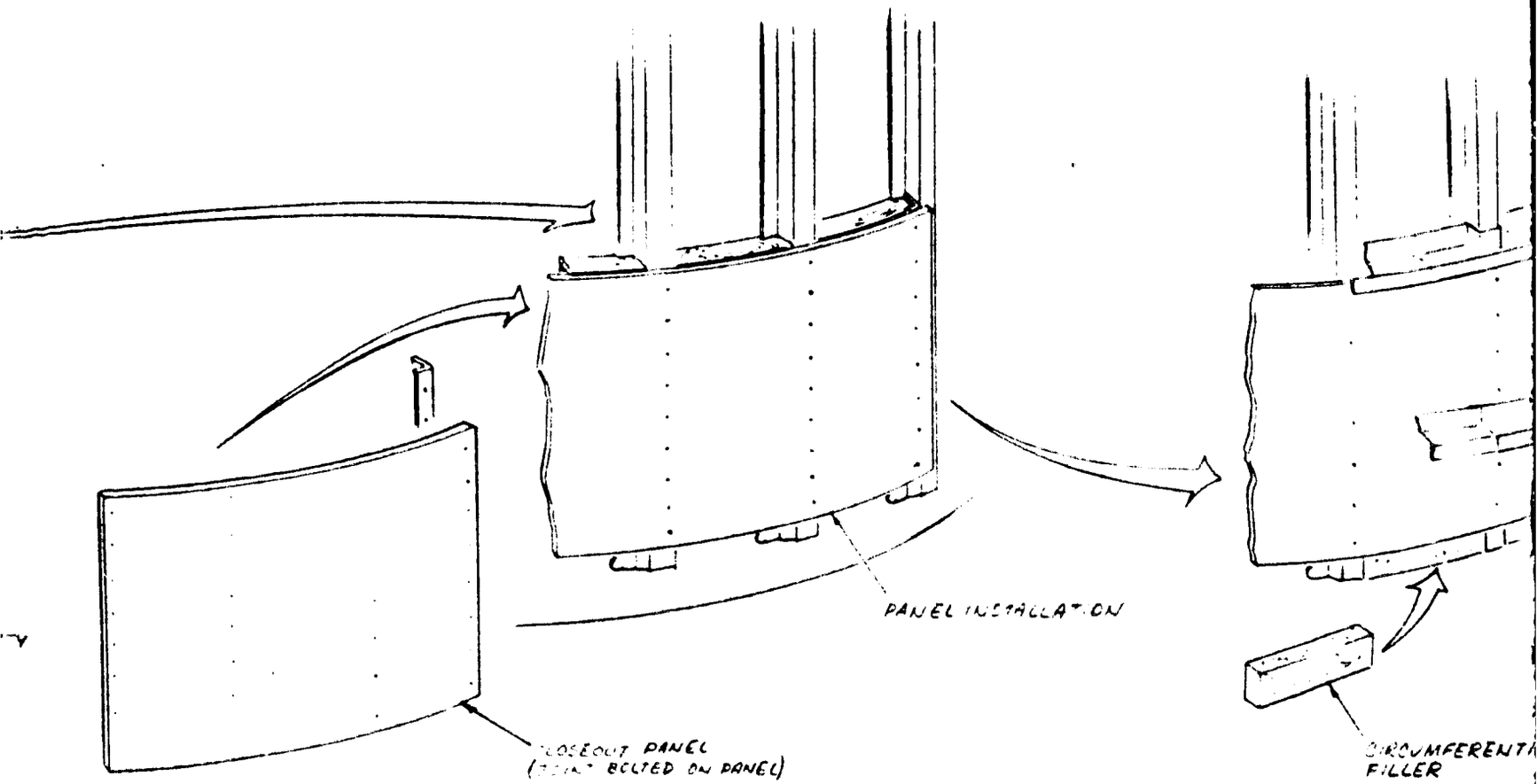

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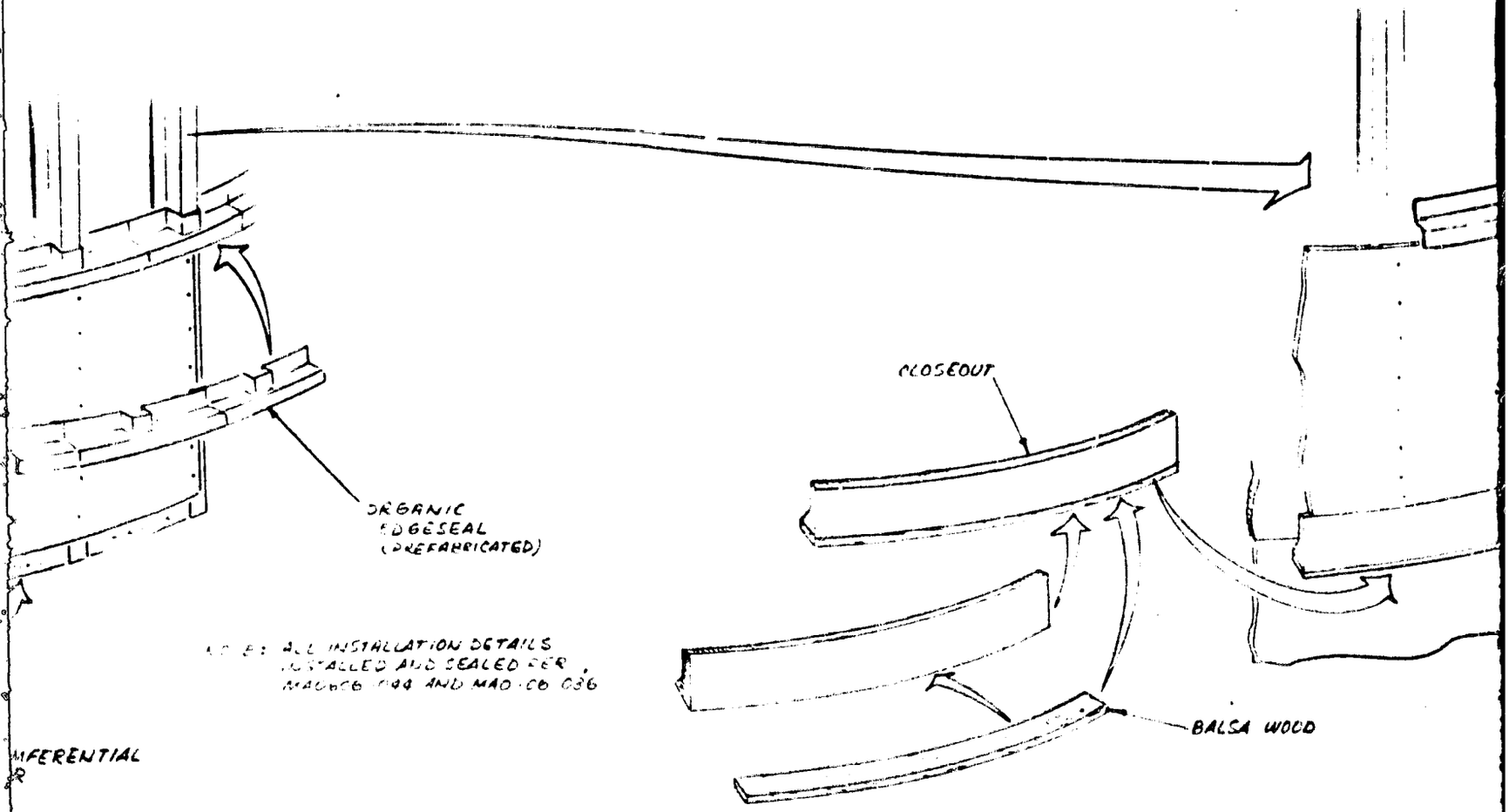

NOTE: ALL INSTALLATION DETAILS
INSTALLED AND SEALED PER
MACHCB 1104 AND MAD-CB 036

IFFERENTIAL

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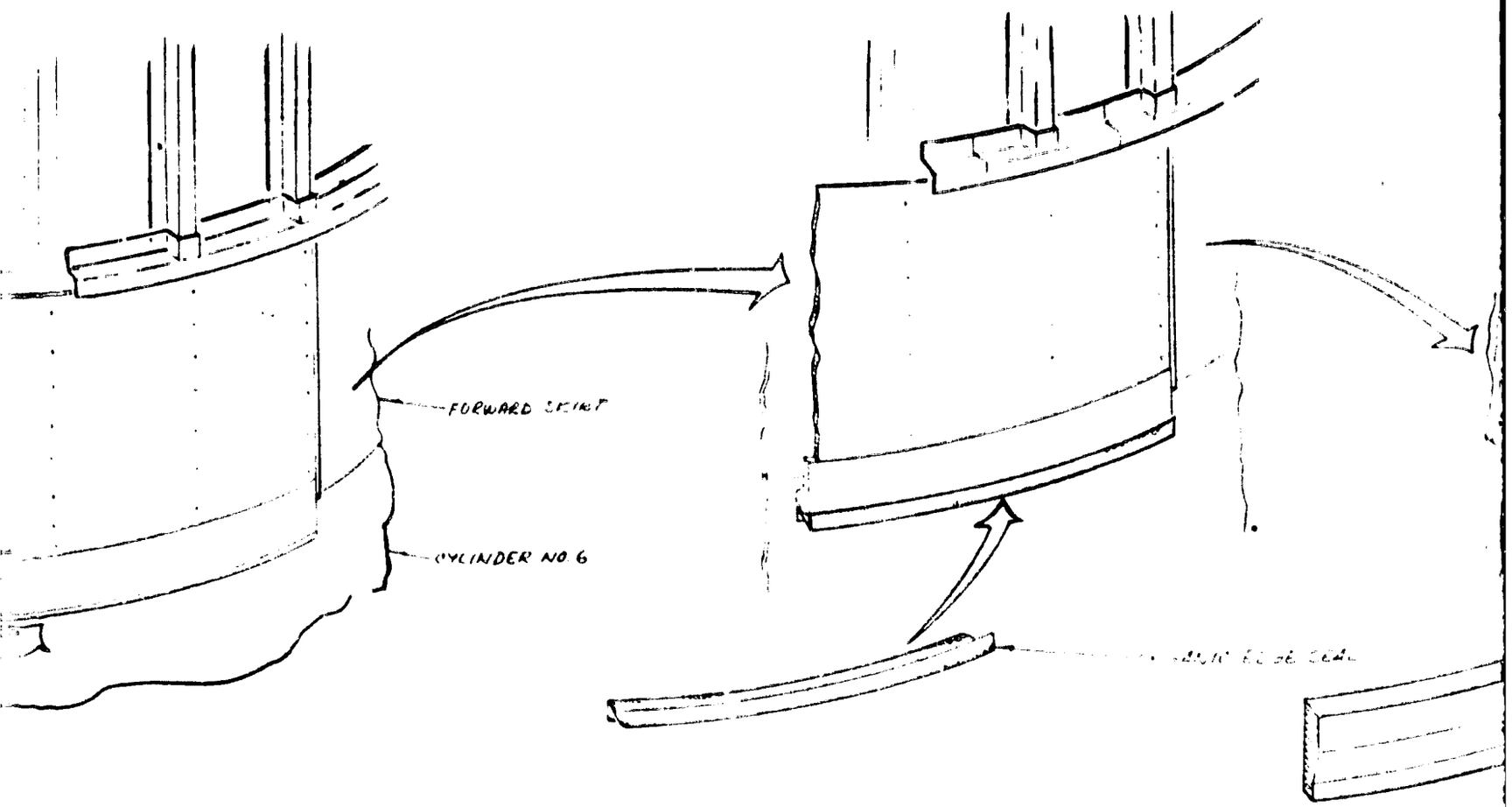

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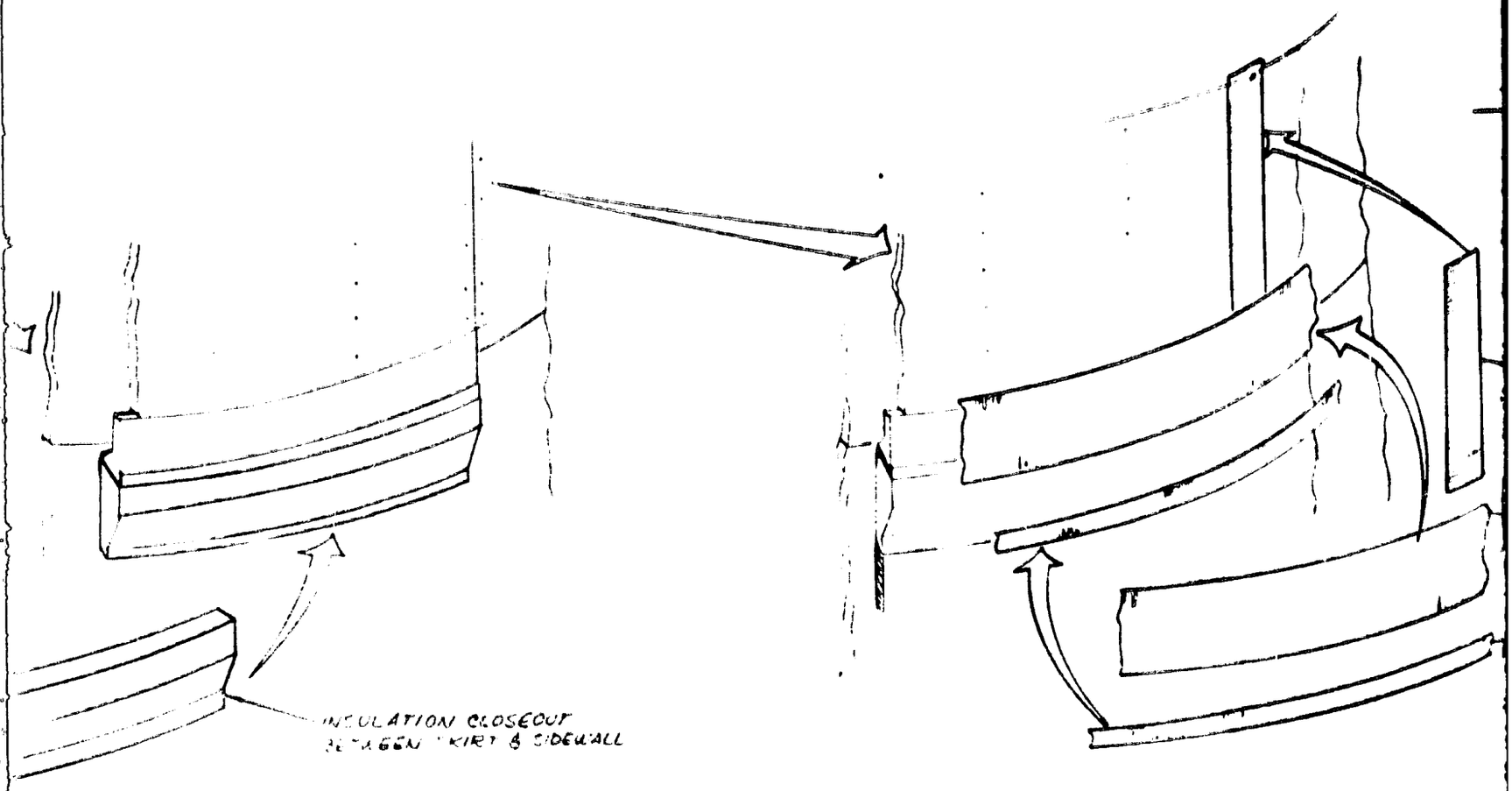

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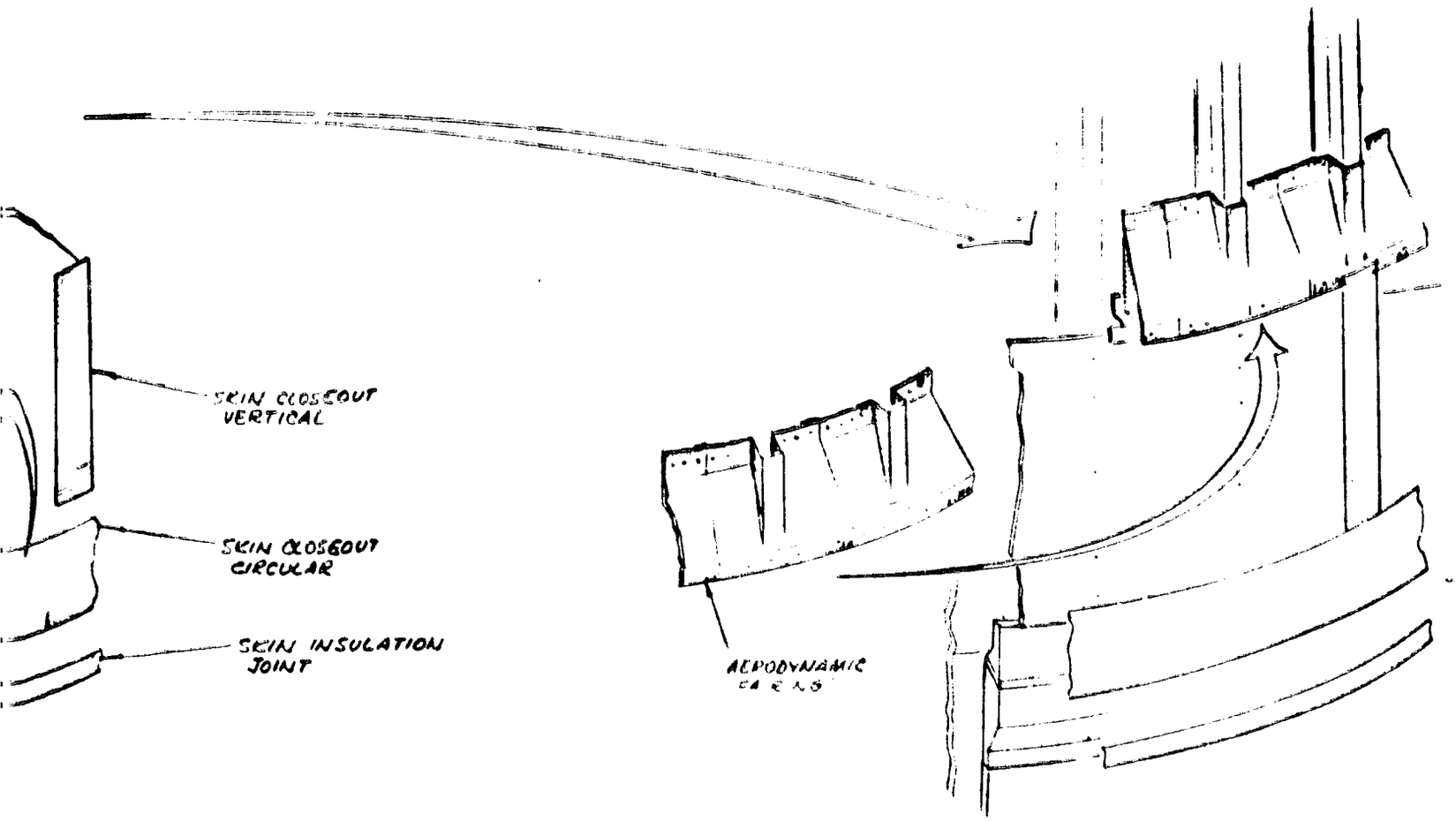


Figure 6.1.3.6-2. Helium Purged Foam Filled Mechanically Attached Over Bonded Foam Blocks

FOLDOUT FRAME 6

2. Fabrication of Honeycomb Panel (MA0605-006):

   (a) Outer Facing Sheet Laminate Test: The face sheet was fabricated from phenolic resin impregnated glass fabric (MB0130-004). Table 15.3.1.4-1 does not establish formal validation requirements for this material. However, as a condition of acceptance, a face sheet test specimen was fabricated within four weeks prior to production use. The specimen was tested for tensile and flexural strength.

   (b) Visual Inspection (completed panel): All finished details were inspected for:

      (1) Proper dimpling of facing laminate

      (2) Barrier film holes

      (3) Broken nodes

      (4) Unfilled core cells

      (5) Foreign objects

      (6) Wrinkles

      (7) Core/laminate voids

      (8) Overall thickness

   (c) Acceptance Test Coupon: A test coupon was fabricated in parallel with the production panel. The coupon was tested for flatwise tensile strength as a final condition of acceptance.

3. Fabrication of the Aerodynamic Fairings (MA0605-006):

   (a) Pre-Production Laminate Test: Same as that specified for the honeycomb panel face sheet.

   (b) Acceptance Test Coupon: A test coupon was fabricated simultaneously with the production laminate and subsequently tested for tensile and flexural strength.

4. Subassembly Installation Process Control (MA0606-044).

   (a) Visual Inspection: All production parts were visually inspected for indication of improper cure, fractures, or other visible flaws.

   (b) Process Control Test Coupons: Metal-to-metal lap shear coupons were fabricated in parallel with all production bonding operations.

c. System Checkout (MA0201-4264):

1. Quarter Panel Vacuum Decay Test: The S-II forward skirt was insulated in four quarter-panel segments (with the exception of the four closeout joints), installed on the vehicle, and followed by final sealing and closeout bonding (MA0606-044). Prior to mating of the quarter-panel segments, each was subjected to a vacuum decay test. The assembly was bagged and subjected to a vacuum of 20 inches Hg. The bag was sealed just above the aerodynamic fairings (Figure 6.1.3.1-1), extended over the exterior of the insulation, and was sealed on the bottom interior surface of the skirt structure. Thus the vacuum decay detected was the result of leakage through the riveted hat section stringers. The maximum allowable vacuum decay was 2 inches of Hg in two minutes.

2. Proof Pressure and Gross Leak Test: Following installation and closeout of the forward skirt (and mating to the S-II stage), the insulation system was pressurized to 1.5 psi and held for 15 minutes. The insulation, while at pressure, was inspected for the following unacceptable conditions:

   (a) Bubbles or blisters forming on the outer skin greater than 0.75 inch in diameter.

   (b) Loss in skin-to-honeycomb bond over two cells.

   (c) Appearance of raised areas greater than 2.5 inches in diameter (or three cell widths) that indicate core-to-aluminum voids.

   If the flow rate at the end of the 15-minute pressurization period exceeded 150 scc/second, the pressure was dropped to six inches of water. The leaks were located by the bubble fluid technique and repaired. The total insulation assembly was accepted by Quality Assurance when visual inspection, flow, and proof pressure requirements were met.

6.1.3.8 Repair and Maintenance

No standard repair procedures were developed.

6.1.3.9 Reliability

Failure modes are identified as leakage and breaking away from structure. Results are presented in Table 6.1.3.9-1.

6.1.3.10 Safety

a. Fabrication and Installation: This insulation system utilizes a large number of detail parts of different types and kinds. The individuals processing these detail parts are exposed to a greater variety of hazards than if they were to process a single variety alone.

Table 6.1.3.9-1. FMEA—Helium Purge, Foam Filled, Mechanically Attached Over Bonded Foam Blocks

Subsystem or Component	Failure Mode	Mission Effects Remarks
Forward Skirt Mechanically Attached	Leakage	Possible mission scrub. Increased boiloff. Loss of helium purge.
	Breaks Away From Stringer	Increased boiloff, shortened mission.

Careful fitting of the insulation detail parts is necessary to insure the integrity of the resulting assembly. Many interfaces are present that would lead to the loss of a positive purge gas pressure if these interfaces are not sealed by fitting the parts to eliminate large gaps or voids.

During the assembly of this system it is necessary to verify that errors of installation are not covered by later installations. In-process inspection and testing must be used to verify that each portion of the system is sound prior to the installation of the next part.

b. Honeycomb Insulation Use: The functional testing of honeycomb insulation systems will include a proof-pressure test of 125 percent of the maximum operating pressure.

The applied honeycomb is relatively fragile and damage is easily incurred after the installation is complete. When the exterior surface is struck by heavy objects the facing sheet can be delaminated. This leads to further delamination by the "zipper" effect when the forward skirt is pressurized. Care should be exercised in the use of honeycomb to insure that no damage to the insulation surface is sustained.

The helim purge gas should be verified to be free of contamination prior to use. When used to insulate hydrogen tanks, 2 percent oxygen in the purge gas could combine with leaking hydrogen to form explosive mixtures. Contamination of any gas with the helium would condense on tank surfaces and solidify and block purge passages or provide a pressurizing source that could separate the insulation from the tank when the solidified gases warmed up and vaporized.

The purge gas should be introduced into the cavities in quantities sufficient to insure that negative pressure does not develop in the honeycomb. When the forward skirt is exposed to cryogenic temperatures the purge gas will contract. A positive pressure within the honeycomb is necessary to insure that minute cracks or openings that are otherwise acceptable will not allow condensible gases to be forced into the purge channels by atmospheric pressure.

After each cryogenic exposure the exterior surface of the honeycomb insulation should be inspected for damage. Any damage should be repaired and tested prior to another cryogenic exposure.

6.1.3.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 36 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 16 weeks.

Subassembly - Not applicable.

Installation - 9 weeks.

Checkout - 1 week.

c. Weight: The total as-installed weight is 0.665 lb/ft^2 broken down as follows:

1. Film (MB0130-024) - 0.0172 lb/ft^2
2. Type II nylon (2 layers) (MB0130-023) - 0.0546 lb/ft^2
3. Foam, 2.2 lb/ft^3, 0.440-inch thick (MB0130-015) - 0.0805 lb/ft^2
4. 3/8 cell, 2.2 lb/ft^3, 0.50 inch thick, honeycomb (MB0130-014) - 0.0914 lb/ft^2
5. Type II nylon (2 layers) (MB0130-023) - 0.0546 lb/ft^2
6. Foam block, 2.2 lb/ft^3, 1.5-inch thick (MB0130-015) - 0.251 lb/ft^2
7. Type 2 adhesive (MB0120-042) - 0.090 lb/ft^2
8. Primer (MB0120-032) - 0.003 lb/ft^2

6.1.4 Spray-On-Foam

6.1.4.1 Description

The spray-on foam insulation system was developed for application on the external surface of the LH_2 tank and was incorporated on the S-II 8 and subsequent stages (V7-531240). The closed cellular structure, thermal conductivity of the blowing agent used, and the cryopumping of gases in the cells near the cold tank surface are influencing factors in determining the thermal efficiency of the foam insulation system.

The configuration of the spray-on foam concept is shown in Figure 6.1.4.1-1. Its components are:

a. Primer — The primer system protects the aluminum tank from corrosion and also provides a surface that enhances adhesion of the foam to the tank surface.

b. Spray Foam, Basic/Closeout — The insulation is a low-density polyurethane foam which is applied directly to the primed substrate with unitized mixing and spraying equipment. The foam is a self-supporting structure that is machined or sanded to its final dimensional configuration.

c. Coating, Seal/Color — A sealant coating is applied to the foam surface to protect against weathering. An additional coating is applied to meet color requirements. This coating system shown in Figure 6.1.4.1-1 was used on the LH_2 tank sidewall where it is exposed to a relatively warm environment. In colder areas such as the forward bulkhead, the spray-on foam was coated with a nylon fabric impregnated with a polyurethane adhesive (wet layup).

A recurring design requirement is the need for transmitting structural loads through the non-structural insulation material. Two methods utilized on this foam system are a "potted-in" threaded insert (hardspot) and a standoff (spacer). Design concepts are shown in Figures 6.1.4.1-2 and 6.1.4.1-3 and a brief description is as follows:

a. Hardspot — A hardspot consists of a foam-filled honeycomb core composite with a potted-in threaded insert. The composite is bonded to the substrate surface.

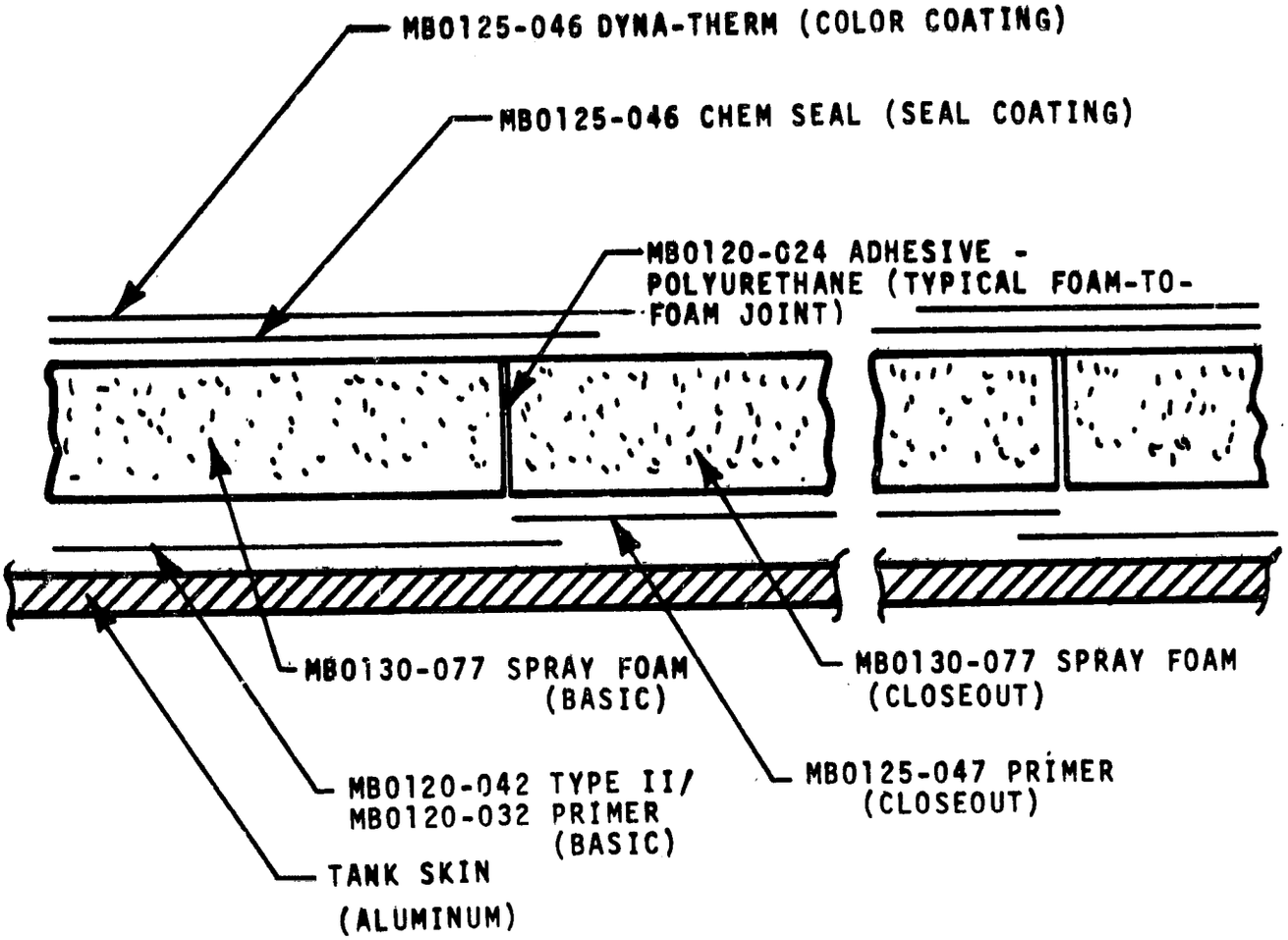
b. Standoff — The standoff (spacer), usually made of a material with low thermal conductivity, is used in conjunction with a threaded insert in the tank structure.

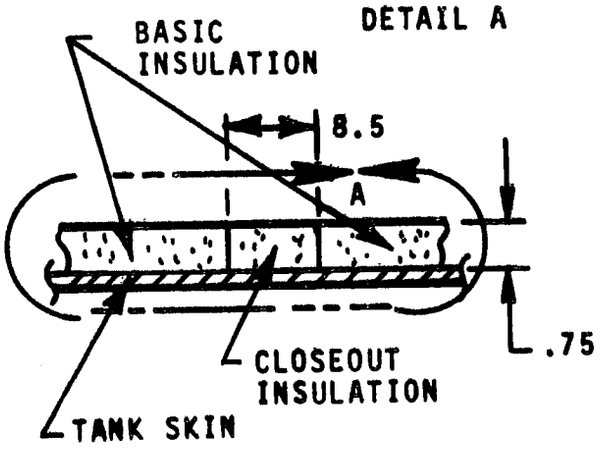
6.1.4.2 Application

a. Utilization: Spray foam insulation combines the properties of low density, low thermal conductivity, and ease of application. Foam as applied to cryogenic tanks provide the most efficient insulation next to evacuated insulations. Thermal efficiency is achieved by condensation of gases contained in the outer cellular structure of the plastic material. This structure also reduces the heat transfer from convection and conduction.

Foam insulations have many applications in addition to their utilization on launch vehicles. It is used for building insulation, refrigeration, storage vessels, and lines. It can also be used for potting and encapsulation of shock-sensitive components and for packaging.

b. Performance Characteristics: Spray foam insulation has been applied to eight S-II stages (S-II-8 through S-II-15). It has been successfully demonstrated through static firing of these vehicles and through launch





PROCESS SPEC MA0606-050

Figure 6.1.4.1-1. Spray-on Foam Insulation

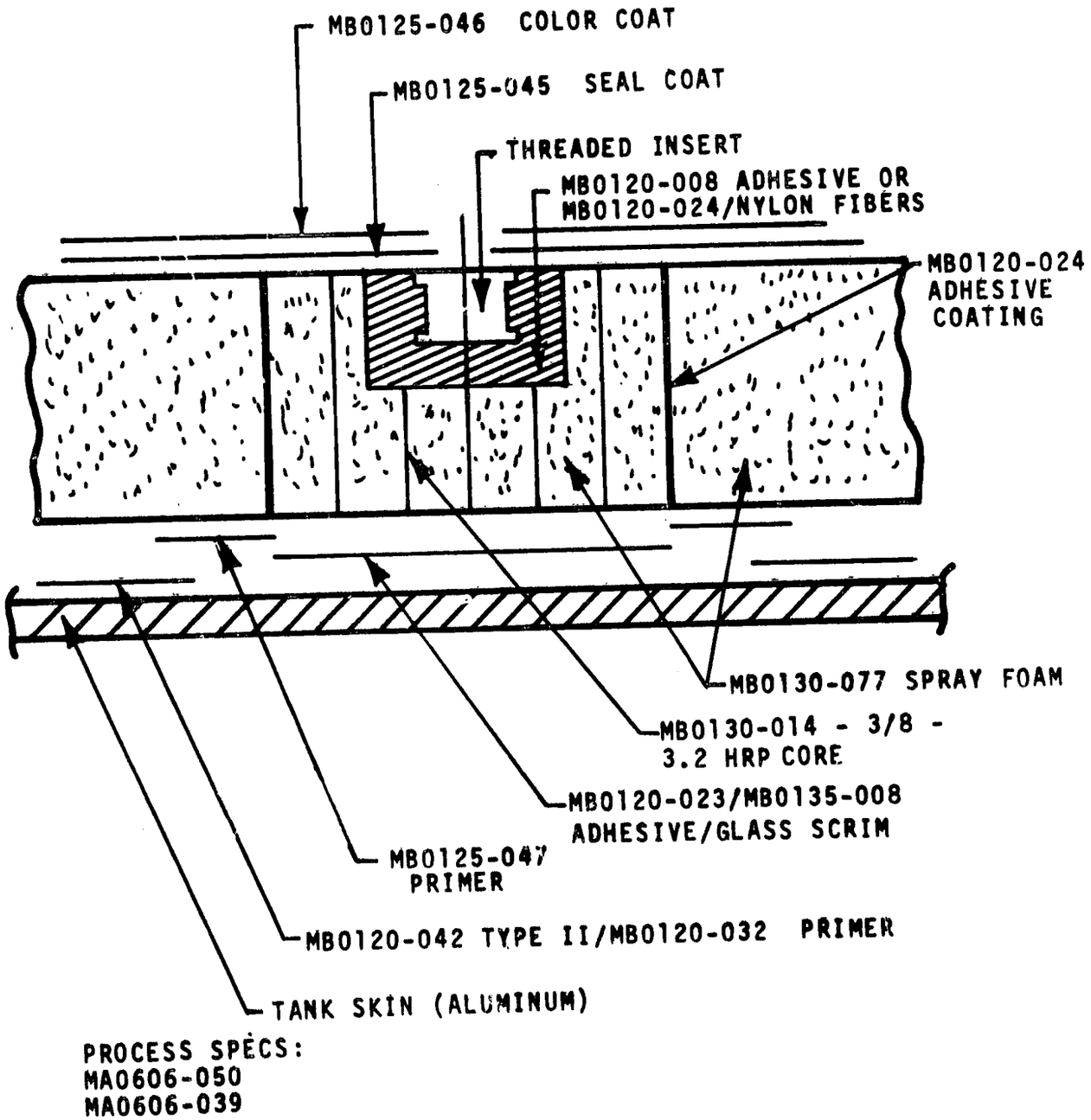


Figure 6.1.4.1-2. Typical Threaded Insert Installation (Hardspot)

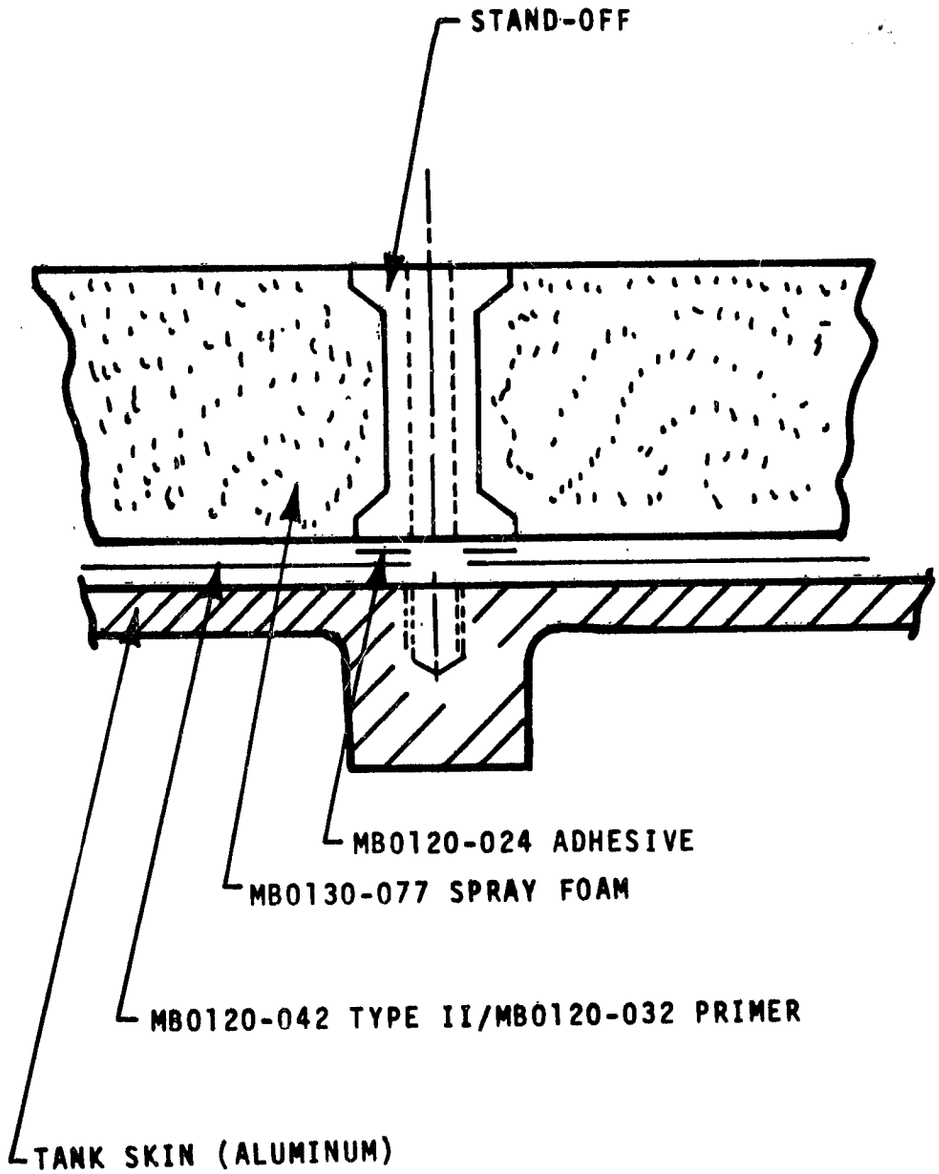


Figure 6.1.4.1-3. Typical Standoff (Spacer) Installation

of four of the vehicles. Thermal performance in flight was within allowable requirements. Heat leak into the LH_2 tank was calculated to be in the range of 65,000 Btu/mission.

c. System Limitations: This system was developed to meet the requirements of the S-II stage program as discussed in Section 5.0. The materials and design are limited to the constraints of that program. Limitations are based on two principal design conditions that prevailed in selection of materials and processing variables: (1) the loss of the insulation during boost and (2) minimization of insulation debris during boost. Tests were conducted (SD 69-734) with oven test shear/temperature profiles approaching the values shown in Figure 4.2.2.4-2.

The results of these tests were satisfactory, indicating acceptable erosion rate with short exposure to aeroheating/aeroshear and temperature up to 600 F.

d. Design Problems: The design of the system and the application of the system to the tanks are quite simple, provided authoritative material properties data are available. The major design problems experienced during development of the spray foam insulation system are summarized in Table 6.1.4.2-1.

e. Design Verification: Tests were conducted to verify adequacy of the design of the spray foam as used on the S-II. The tests discussed in Reference 31 included:

1. Tests on the X-15 research rocket plane to simulate the S-II aeroheating/aeroshear profiles. Tests demonstrated the capability of spray foam up to 600 F.

2. Altitude/aeroheat tests and cryogenic strain tests to verify material and processing of foam. Three different batches of material were tested.

3. Cryogenic strain tests to verify application equipment.

4. Altitude/aeroheat tests with simulated temperatures and altitude pressures to verify coating system over foam.

5. Verification of thermal characteristics of foam under repeated fill and drain cycling and under extended environmental exposure. Minimum thermal degradation was experienced after 30 cycles and 210 days of humidity/salt spray exposure.

6. Verification of the spray foam under combined environments of cryogenic cycling and vibration with heating.

7. Verification of foam's ability to retain its structural properties on long-term exposure to the natural environments. Specimens exposed for up to 180 days of natural exposure and 50 hours of accelerated environmental exposure were tested to maximum strain levels and under simulated aeroheating. Foam was not affected by exposure.

Table 6.1.4.2-1. Spray Foam Design Problems and Solutions

Problems	Solutions
Poor bond of foam to MB0120-032 primer	Developed MB0120-042 primer to be put over MB0120-032 primer to increase foam bondability to substrate
Corrosion of aluminum under areas protected only with MB0120-042 primer (on stage and test articles)	1. Improve masking and cleaning processes 2. Developed MB0125-047 primer to replace MB0120-042 primer in closeouts and other areas using only MB0120-042
Selection of moisture barrier coating with minimum debris during launch	1. Developed coating that would melt and drip on heating; no ballooning or loss of large pieces of coating; coating good for ultraviolet protection of foam 2. Developed outer coating to maintain white color of surface
Divots in foam - complete seal of insulation difficult (on detanking, through leakage sources in foam)	1. Better seal of foam implemented 2. Known leak areas isolated
Protection of foam in protuberance areas	Developed cork over foam and cork-foam rails to protect foam
Debond of cork/foam rails	1. Reduced adhesive bond line thickness to match thermal shrinkage of tank wall 2. Changed bonding process to insure uniform thickness
Quality control (bond integrity difficult to verify, quality of foam variable)	1. Provided density check prior to spraying 2. Provided in-process test samples (cryostrain tests) 3. Developed statistical destructive inspection (PQV) techniques
Spray equipment - malfunction and clogging of spray guns and associated equipment	1. Planned cleaning and preventive maintenance program 2. Start each foaming operation with freshly cleaned equipment

8. Foam system, including repairs, was verified on a large-scale tank. The foam proved its thermal and structural integrity after exposure to cryogenic cycling and maximum strain levels. The insulation field repair methods and techniques were successfully demonstrated.

9. Foam system has been successfully demonstrated, both thermally and structurally, on four Apollo flights with the S-II stage operating as required.

6.1.4.3 Thermal Performance

The thermal performance characteristics of spray-on foam are given for a large tank containing LH_2 which is subjected to both ground-hold and launch environments. The hot day ground-hold environment which was used is discussed in Section 4.1 and is defined in Paragraph 7.3.1.1. The launch environment used is the maximum aerodynamic heating trajectory for the LOR mission shown in Figure 4.2.2.3-1. The temperature distribution, heat rate, and accumulated heat to the LH_2 as presented applies to large areas of the basic tank sidewall insulation.

The effective insulation system thermal conductivity as a function of temperature is presented in Figure 6.1.4.3-1. The mean value used for design is 0.12 Btu/in.-hr.-F-ft.^{2}. An analytical model for determining the thermal conductivity of closed-cell polyurethane foam is presented in Section 7.4.1. This model assumes parallel heat-flow contributions from solid conduction in the resin of the cell walls, gas conduction within cells, and radiation from cell to cell. The K values predicted by this model have been verified experimentally (see Section 7.4.1). These K values were used to determine the temperature distribution presented in Figure 7.3.1.4-3. The maximum external surface temperature of 560 F occurs just prior to S-II ignition. The hot day ground-hold heat rate to the LH_2 is 80 Btu/hr.-ft.^{2}. The accumulated mission (including 90 seconds of ground-hold) heat leak to the LH_2 is 12 Btu/ft.^{2}.

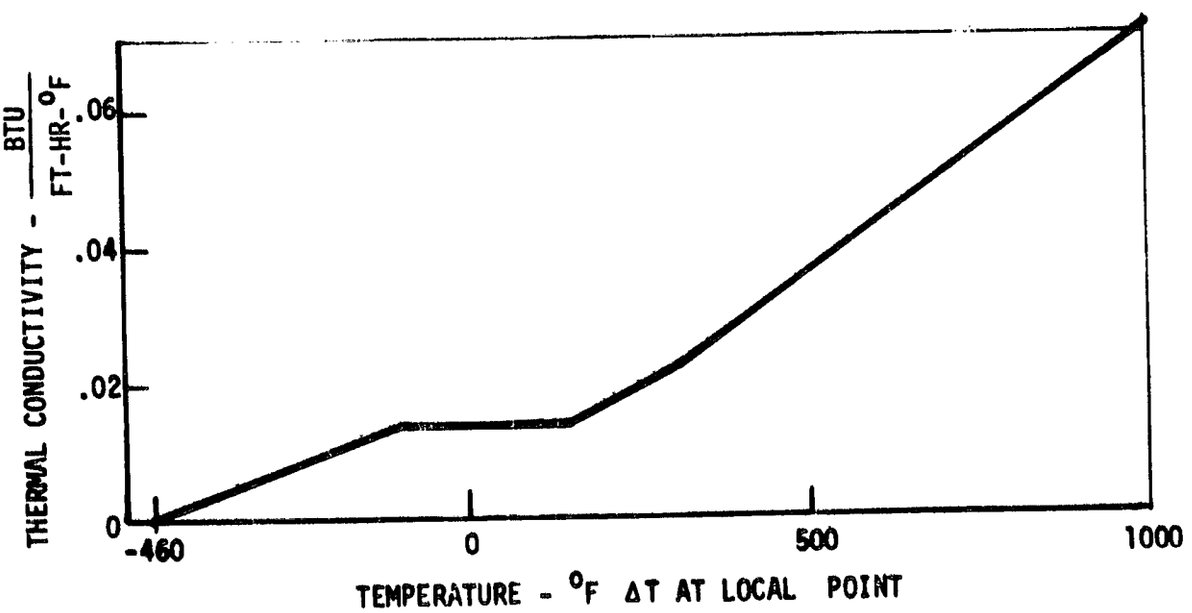


Figure 6.1.4.3-1. Effective Thermal Conductivity of 2-lb/ft^2 Density Spray-on Foam Insulation

6.1.4.4 Structural Performance

The spray foam insulation system has demonstrated its ability to withstand the stresses and strains induced from tank strain levels due to internal pressure, and the differences in thermal contraction and expansion rates between the aluminum and foam. The differences in the thermal contraction rates between the foam and the aluminum skin contributes the most (approximately 90 percent) of the stress developed in the foam.

Since the foam is of lightweight construction and is continuously bonded to the tank skin, its dynamic response and properties are the same as the tank skin. Hence, stresses resulting from dynamic effects are considered negligible.

Of prime importance from a structural analysis standpoint for spray foam are:

a. It should be noted that the spray foam exhibits a visco-elastic behaviour different from the normal elastic behaviour of metals. The structural analysis of organic materials is discussed in Section 8.0.

b. Proper application of primer to the tank skin to prevent failure of the foam to tank wall bond.

6.1.4.5 Materials and Processes

a. Materials:

1. Foam: Two-component, flame-retardant polyurethane foam, two-pound density, for spray application (MB0130-077).

2. Primers:

(a) Adhesive primer, epoxy base resin, two-component, heat curing (MB0120-032).

(b) Adhesive primer, polyester/isocyanate, two-component, room-temperature curing (MB0120-042 Type II).

(c) Epoxy amine corrosion preventive primer, two-component, room-temperature curing (MB0125-047).

3. Adhesive resin: Polyurethane, two-component, low-temperature curing (MB0120-024).

4. Adhesive, modified: Epoxy, two-component, low-temperature curing (MB0120-023).

5. Honeycomb core, heat-resistant phenolic 3/8-inch cell, 3.2-pound per cubic foot density (MB0130-014).

6. Glass fabric, scrim type (MB0135-008).

7. Exterior Coatings:

   (a) Elastomeric polyurethane base coating material, two-component (MB0125-045).

   (b) Vinyl color-coat material, single component (MB0125-046).

b. Process: Application of spray-on foam to the configuration specified in Figure 6.1.4.1.1 is processed in accordance with the requirements of MA0606-050.

1. Material Storage and Handling: All materials are stored and handled in accordance with the requirements of applicable specifications.

2. Surface Preparation:

   (a) Aluminum substrates are cleaned and etched for primer application in accordance with the cleaning specification (MA0610-023). Special masking procedures are available (MA0308-1033) to prevent etchant entrapment and attendant corrosion in the preparation of weld closeout areas.

   (b) Primed or painted surfaces are solvent cleaned with MEK.

   (c) Other surfaces are cleaned in accordance with specific requirements of the process specification (MA0606-050).

3. Primer Application: Subsequent to cleaning all bare aluminum surfaces which are to be foam-insulated must be primed to afford maximum insulation adhesion and corrosion protection.

   (a) An epoxy primer (MB0120-032) is applied in accordance with the process specification (MA0106-045). Since a heat cure is required, the primer is applied to subassembly components.

   (b) An epoxy amine primer (MB0125-047) is applied in accordance with the process specification (MA0606-050). Primer thickness is maintained between 0.0006 and 0.0015 inch to afford maximum cryogenic strain compatibility.

   (c) A Type II primer (MB0120-042) is applied in accordance with the process specification (MA0606-050). The material provides an adhesive tie coat between the foam and the primed substrates. This primer will not provide corrosion protection and, therefore, may not be applied over bare aluminum.

4. Load Transfer Attach Points: When required, attach point systems are installed to the tank wall and foam insulation is subsequently sprayed around them. Two types of load transfer systems are utilized: standoff spacers (Figure 6.1.4.1-3) and core-foam composites (Figure 6.1.4.1-2).

(a) Standoff spacers are bonded to the primed aluminum tank wall using polyurethane resin (MB0120-024). The steel spacers are bonded under pressure provided by installing a fastening bolt and torquing to 15-20 foot-pounds. The assembly is cured 24 hours at 70 F minimum before the bolt is removed.

(b) Core-foam composites are bonded to a bare aluminum tank wall using epoxy adhesive (MB0120-023) with scrim carrier.

(1) Detail Assembly: 3/8-3.2 HRP honeycomb core (MB0130-014) having been completely filled with spray foam is processed (MA0606-039) to fabricate the attach point composite detailed in Figure 6.1.4.1-2. Type II, Class II threaded inserts are potted into place using polyurethane adhesive (MB0120-024) mixed with 6 parts by weight nylon fibers. The adhesive system is allowed to cure 24 hours at 70 F prior to handling and 48 hours prior to torque testing.

(2) Assembly Bonding: Following removal of all primers from the tank surface per MA0610-022 the bare aluminum is etched per MA0610-023. Epoxy adhesive (MB0120-023) is combined with glass scrim cloth (MB0135-008) to provide a final tape weight of 0.20 to 0.27 gram per square inch. The adhesive tape is applied to the core-foam composite and a thin butter coat of epoxy adhesive (0.03 gram per square inch maximum) is applied to the aluminum faying surface. The core foam composite is positioned on the tank wall under a maximum pressure of 8 psi and allowed to cure 48 hours at a temperature of 60 to 90 F. The first 12 hours of cure must be above 65 F and under pressure.

(3) Any bare metal still exposed following the bonding operation must be coated with epoxy-amine primer (MB0125-047) per MA0606-050. The primer should overlap onto the core-foam composite to assure complete coverage of the tank wall.

5. Foam-to-Foam Joints: Cut edges of cured spray-on foam and core foam composites which will form a foam-to-foam joint must be coated with adhesive resin (MB0120-024). The amount of resin must be sufficient to obtain a glaze coat on the surface of the cut foam. Surfaces which extend to the tank wall are coated to a point 0.07 ± 0.06 inch from the tank wall. To prevent primer debond and possible foam damage during cryogenic exposure, the resin must not contact the primed tank. Foam must be applied between 12 and 24 hours of resin application.

6. Mixing and Delivery:

(a) Equipment: Foam is applied to the properly prepared substrate using a certified internal mixing spray foam delivery system.

(b) Environmental Controls: During foam delivery, environmental control is extremely critical for the formation of quality insulation. A restrictive "Processing Permitted" temperature-humidity envelope is presented in the process specification (MA0606-050) which limits the available moisture in the surrounding air. In addition, it is necessary that the entire metal substrate and its surrounding environment be maintained at an equilibrium or stable temperature to prevent formation of a high-density, cryogenically non-compatible rind at the insulation interface with the tank wall.

(c) Mixing: The spray equipment must be adjusted to provide the component ratio specified on the container. Too high a foam mix ratio (excess isocyanate) will result in a brittle friable foam, while too low a ratio (excess polyol) will result in a dimensionally unstable foam.

(d) Delivery: Each application of foam is accompanied by moving the spray impingement area from a disposable surface to the detail part without interrupting dispensation. The drawing thickness requirements must be exceeded in one pass of the impingement area.

7. Cure: The sprayed foam shall remain undisturbed for 16 hours minimum under the temperature-humidity requirements established for spray application prior to cutting or trimming. An additional 40 hours cumulative cure time at 60 to 90 F and 70-percent relative humidity maximum is required prior to application of finish coatings. A total cure of 72 hours is required prior to cryogenic exposure of the tank wall.

8. Protective Coatings: The cured and trimmed foam must be protected from weather exposure, fungus, and discoloration by the application of polyurethane coating material (MB0125-045) and color top coat (MB0125-046) in accordance with MA0608-015. Three coats of polyurethane and one coat of the vinyl top-coat are required.

6.1.4.6 Manufacturing

a. General Description: The foam insulation used on the S-II LH_2 tank was applied by spray gun to large cylinder subassemblies approximately 8 feet high and 33 feet in diameter. The 33-foot-diameter forward LH_2 bulkhead was also spray foamed as a major subassembly. The foam insulation was subsequently machined to the prescribed thickness.

After the six cylinders and bulkheads were welded and after tank pressure testing and weld X-ray, spray foam was applied over the weld areas closeouts to complete the basic spray foam application. All of the spray foam was applied by rotating the completed stage past a fixed tool post that held the oscillating spray guns and machining heads.

Prior to the spray foam operations, the tank surfaces were primed with primer systems. The base primer was an oven-cured modified epoxy primer that was applied by spraying and curing at the quarter panel and bulkhead assembly level. The secondary primer ("M" primer) was a room-temperature curing primer that was applied with brushes after a MEK wipe of the previously primed surfaces just prior to spray foaming. The bare metal surfaces at the weld zones were chemically cleaned and primed with a sprayable type of epoxy based primer and room-temperature cured.

The spray foam used was a two-component liquid system that was delivered through separate hoses under pressure and mixed in the spray gun prior to being passed through the special spray nozzle onto the work surface. The gun was located approximately 18 inches away from the surface and was oscillated to give an even coating over the sprayed surface. The foam rose within five seconds of mixing and the thickness was controlled by the amount of liquid applied. Spray guns delivered from 2 to 10 pounds of liquid per minute and the output when coupled with speed over the surface determined the rough thickness of the finished foam.

After the spray foam was cured, the surface was machined to the required thickness and hand-sanded to obtain a smooth blended surface. Hard spots and standoffs for attach points were located with locating templates. Part of the hardspots and standoffs were bonded in place prior to foaming; others were installed by cutting out a cleared area in the foam and bonding the standoff in place, then re-spray foaming around the standoffs filling the void area until flush. The foam was trimmed and sanded flush with the adjacent area. The entire foamed surface was vacuum cleaned and the surface blemishes were filled with a thioxotropic paste using a wood spatula. A nylon wet layup was applied to the bulkhead area only. The area was covered in gore segments, applying the adhesives first, then the nylon fabric in precut sheets and then saturating the surface with adhesives and squeegee the surface out, removing air bubbles until smooth.

The bare foam surfaces of the tank side walls were sanded, vacuumed, and blemish-filled the same as the bulkhead. The final coatings of the side-wall consisted of a moisture barrier and a color coat, both of which were applied with standard paint rollers. The finished surfaces were then covered with a padded protective hard cover which provided protection through subsequent operations. A general manufacturing flow of the spray foam operations is shown in Figure 6.1.4.6-1.

b. Tooling: Tooling consisted of:

1. Spray foam tool posts and skates to support the spray gun and machining head.

2. Spray foam gun and pumping machine (as a unit), Lemco Model #510 was considered part of the tool post.

3. Holding and rotating fixtures for the cylinders and bulkhead and total stage. All rotating tools had variable speed control devices.

4. Foam masking tools for various specialized areas.

5. Locating and holding tools for locating and bonding hardspots and standoffs.

6. Phenolic rotary cutter for general machining and cutouts.

7. Phenolic knives for general hand trimming.

c. Facilities and Equipment: Facilities consisted of:

1. Temperature and humidity controlled work areas.

2. Standard factory utilities including vacuum.

3. Fumes and dust evacuation systems.

Equipment items required were:

1. Precision scales 0-1000 grams for measuring mix foam ratios and adhesive mixes.

2. Breathing masks for spray foam operators.

3. Hydrothermograph for temperature and humidity monitoring.

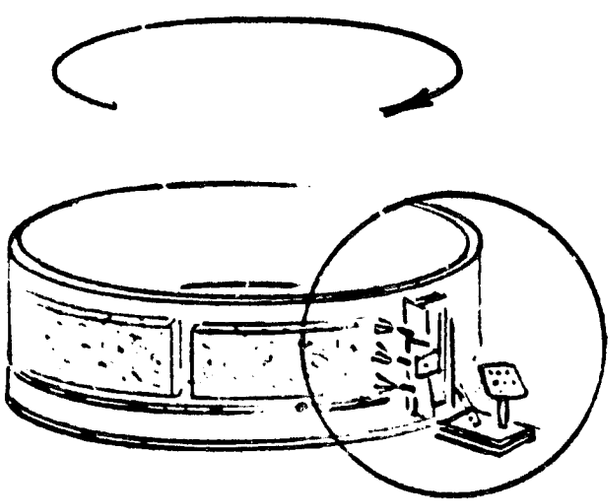
4. Proximity measuring device for measuring foam thickness.

6.1.4.7 Quality Assurance

The quality control techniques employed for the application of spray-on-foam-insulation(SOFI) were unique. Emphasis was placed on positive control of all variables (material, equipment, and environment) prior to the actual preparation of the foam insulation. This emphasis on proper preparation was justified by the fact that a subassembly to be insulated with approximately 800 square feet of insulation could require as much as two weeks preparation time and only 20 minutes for foam application. For that reason, Receiving Inspection of the SOFI raw material will be included in this section of the report.

a. Raw Material Control: With the exception of the foam raw material (MB0130-077), the materials used in the SOFI composite were handled in a manner identical to that described for other insulation systems. However, since pre-process control was deemed critical for this insulation system, Receiving Inspection of the SOFI raw material is covered here in detail.

1. Receiving Inspection (MB0130-077): The acceptance tests performed by NR on each receival of SOFI raw material were critical to end item quality, since the ultimate spray ratio of the two-component system was determined from these tests. There were three separate series of tests performed on each receival.



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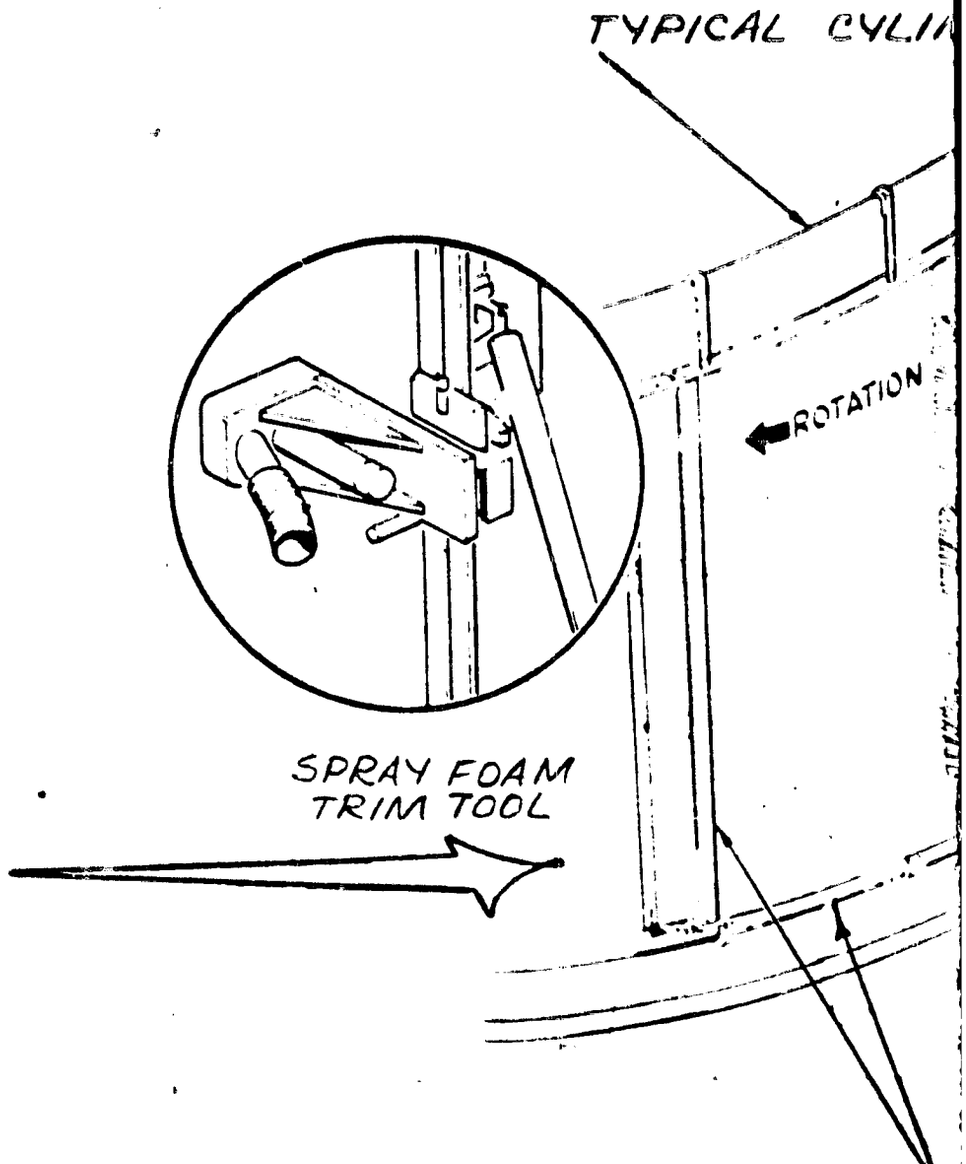

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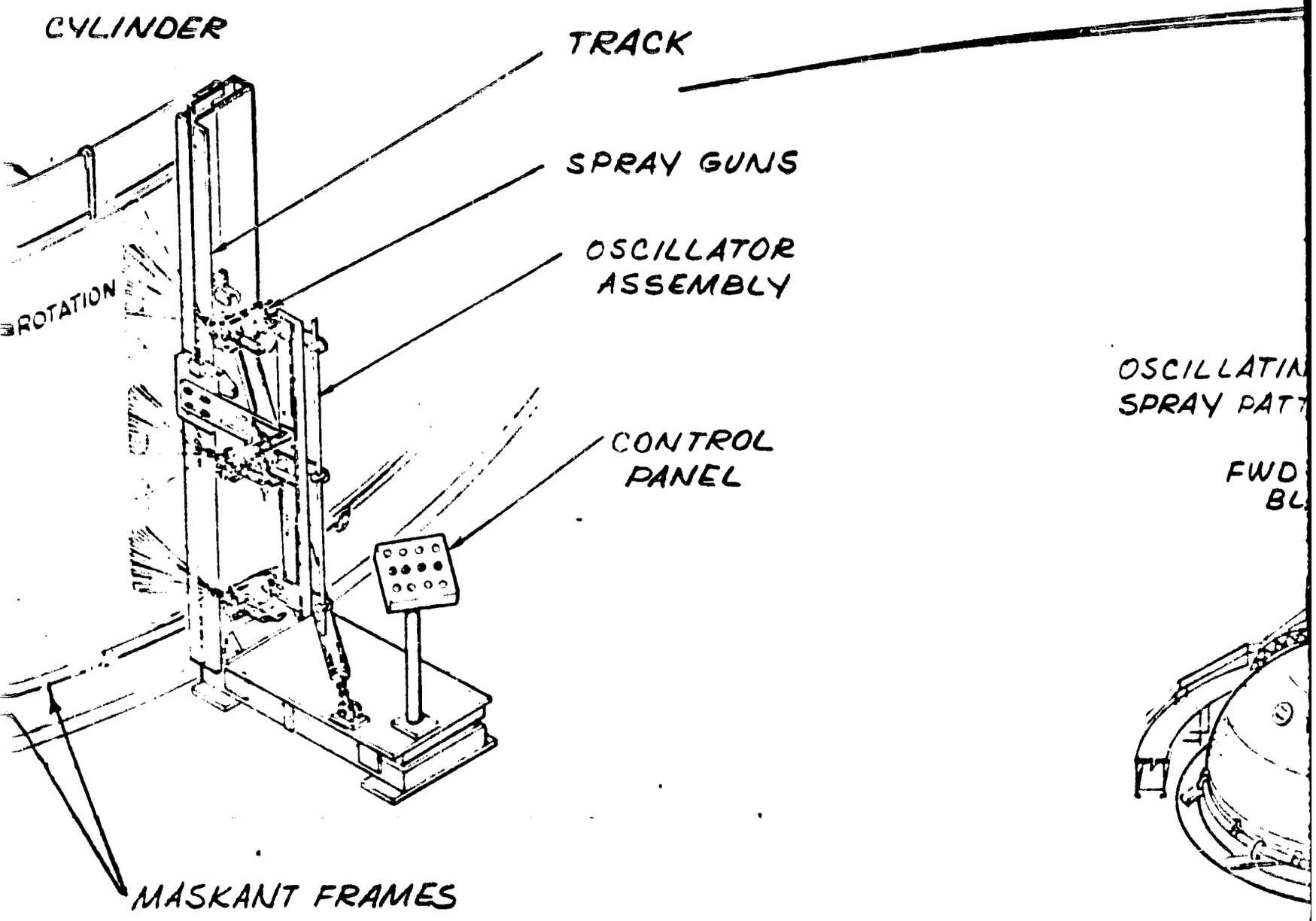

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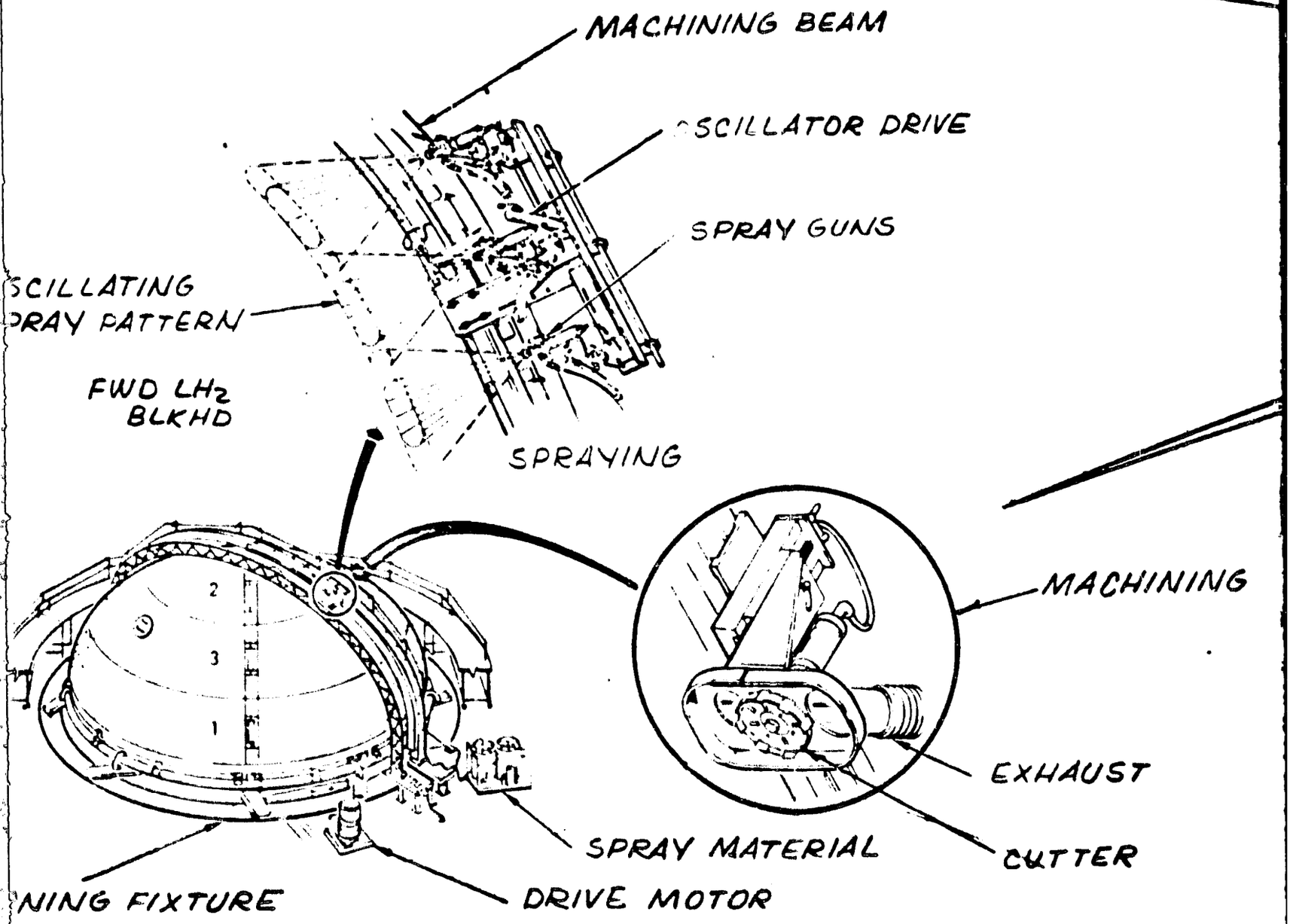

FORWARD LH_2 BULKHEAD SPRAY FOAM APPLICATION AND MACHINING

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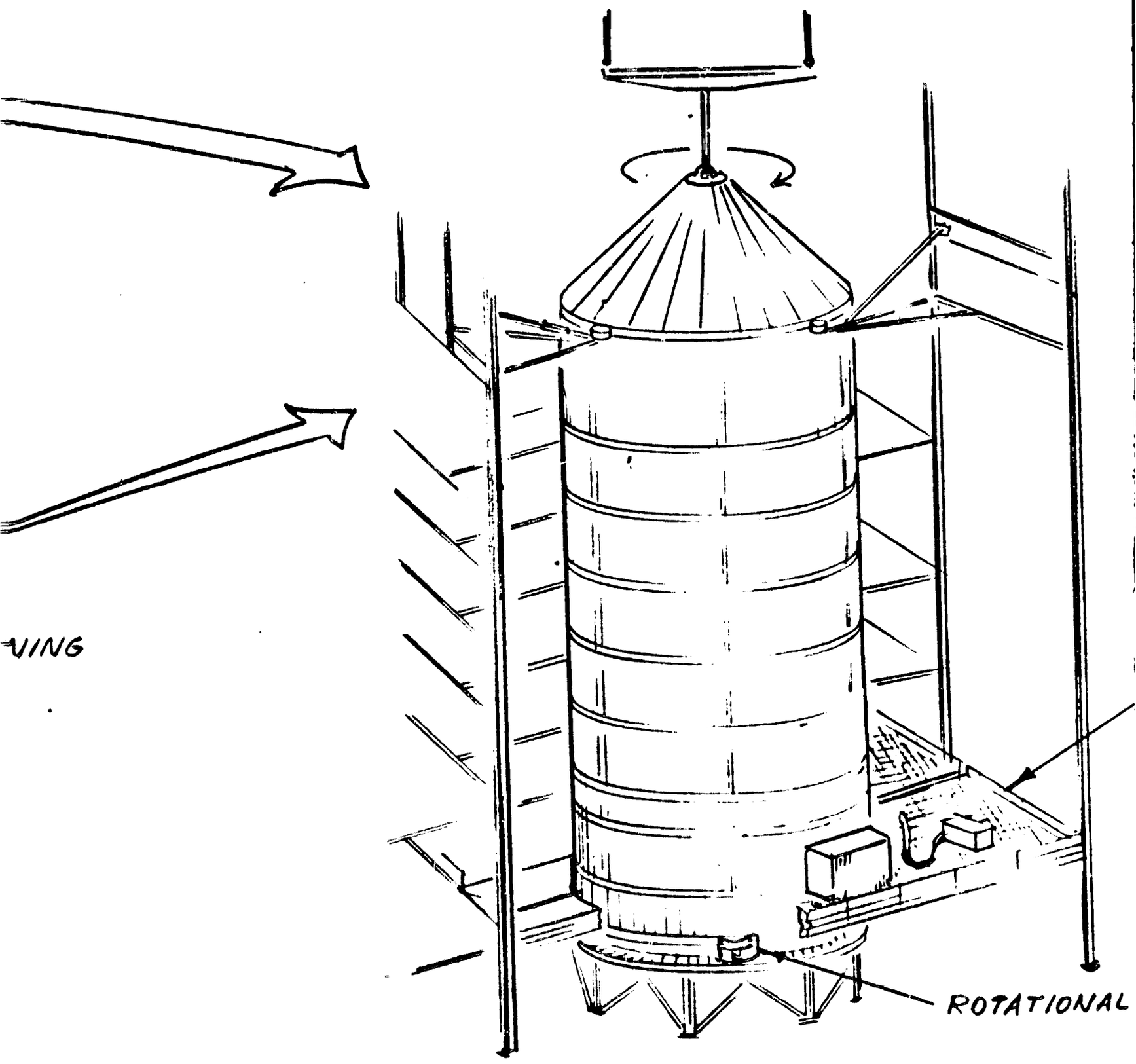

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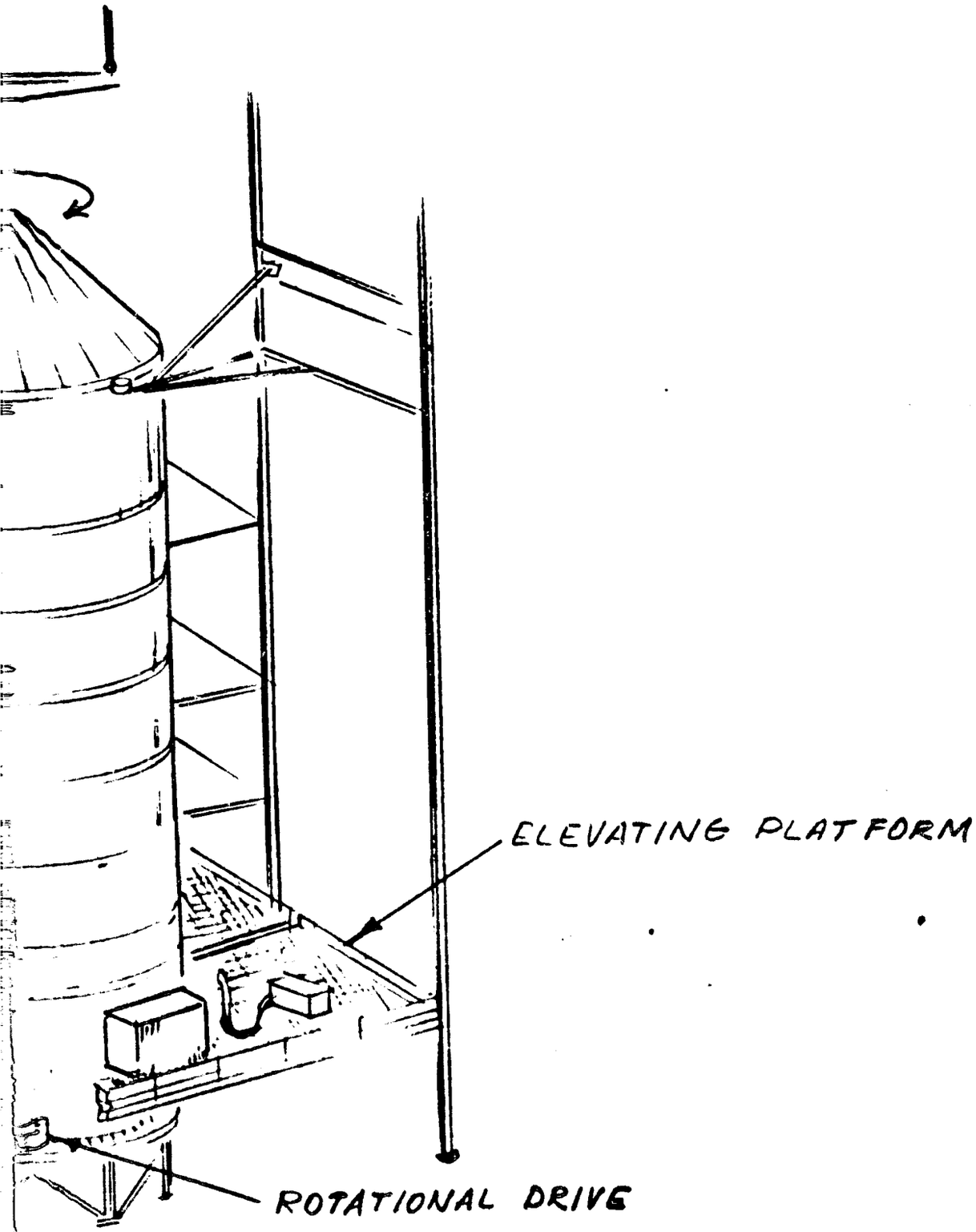

Figure 6.1.4

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Figure 6.1.4.6-1. Spray Foam Application

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(a) Foam Component Properties: Each component was sampled and tested for the properties noted in Table 6.1.4.7-1.

Table 6.1.4.7-1. Foam Component Properties

Property	Requirement	
	Component A	Component B
Viscosity (cps)	275 ± 125	340 ± 100
Specific gravity	1.237 ± 0.006	1.208 ± 0.012
Amine equivalent	134 ± 3	-
Water content (%)	-	0.1 (maximum)
Hydroxyl numer	-	505 ± 20
Fluorocarbon content (%)	-	28 ± 2

From these values the optimum spray ratio by weight was established for that particular lot of foam by the following formula:

$$\frac{A}{B} = \frac{(HN - FC\ (HN)\ )\ AE\ (1.06)}{56{,}100}$$

where

A = weight of Component A
B = weight of Component B
AE = amine equivalent
HN = hydroxyl number
FC = fluorocarbon content (decimal)

(b) Foam Mixing Properties: Using the ratio established above, the hand mix properties shown in Table 6.1.4.7-2 were determined.

Table 6.1.4.7-2. Foam Mixing Properties

Property	Requirement
Cream time (sec)	5 to 8
Rise time (sec)	25 maximum
Tack-free time (sec)	25 Maximum
Density (lb per cu ft)	2.0 (+0.2, -0.3)

(c) Sprayed Foam Properties: Again using the spray ratio established from the foam component properties, test samples of foam were sprayed using production spray equipment. Tests were performed as noted in Tables 6.1.4.7-3 and 6.1.4.7-4.

Table 6.1.4.7-3. Physical and Chemical Properties of Cured Foam

Property	Requirement
Density (lb per cu ft)	2.0 (+0.2, -0.3)
Coefficient of linear thermal expansion (room temperature to -300 F, perpendicular-to-the-rise (in./in. °F)	6.9×10^{-5} maximum
Flammability	Nonburning

Table 6.1.4.7-4. Mechanical Properties of Cured Foam

Property	Test Temperature (± 5°F)	Average Value (psi, minimum)	Individual Value (psi, minimum)
Compressive strength (parallel-to-the-rise)	70	25	20
Tensile strength (parallel-to-the-rise)	70	48	38

Upon successful completion of the above series of tests, the foam raw material was accepted for production use.

2. Validation: Table 15.3.1.4-1 defines the level of validation performed during the application of SOFI to the Saturn S-II vehicle.

b. Subassembly Process Control, MA0606-050:

1. Primer Application (Figure 6.1.4.1-1): Three different primer systems were utilized during the application of SOFI. The quality control measures for surface preparation were common to all three systems and were as stated in Paragraph 6.1.1.7. Post-application quality control checks were as follows:

(a) MB0120-032: Primer thickness was verified by the use of a Fischer Permascope.

(b) MB0125-047: In addition to thickness verification, a tape test for adhesion was performed using Scotch 401 tape.

(c) MB0120-042, Type II: Visual inspection was performed to verify 100-percent coverage.

2. Spray Foam Application:

(a) Pre-Process Control: Pre-process control is defined as those steps required to provide assurance that the SOFI was applied by qualified personnel using certified equipment, working in a safe, environmentally controlled facility.

(1) Equipment Certification: Each model number of production spray equipment was required to have a demonstrated capability of meeting the density, tensile strength, and cryogenic strain compatibility requirements of MB0130-077. In addition, each unit of each model number was required to have a demonstrated capability of meeting the specification requirements for density and tensile strength.

(2) Environmental Control: Immediately prior to commencement of spray operations it was verified that the ambient temperature, relative humidity, and oil/moisture content of the atomizing air employed by the spray equipment were within the requirements of MA0606-050.

(b) In-Process Control: In-process control for SOFI operations consisted of final spray equipment checkout, visual inspection during processing, and the preparation of process control test coupons simultaneously with the production hardware.

(1) Spray Equipment Checkout: Just prior to commencement of SOFI application the raw material delivery hoses were disconnected at the spray head and samples were taken, weighed, and proper ratio by weight verified. As a final check, the delivery hoses were reconnected, and foam was sprayed into a paper cup to verify delivered foam density.

(2) Visual Inspection: The inspector was stationed in the immediate vicinity of the hardware during SOFI application. Any suspect areas noted during foaming were documented and inspected separately after final machining operations.

(3) Process Verification Coupons: Foam samples were taken from each spray unit just before and just after application of the SOFI to the production hardware. Proper density was verified from these samples. Cryogenic strain compatibility coupons also were processed simultaneously with the subassemblies. When multiple spray units were employed (as in the case of LH_2 Cylinders 2 through 6 involving three spray units), the dog bones were located on the subassembly in such a way that each spray unit applied foam to two test specimens. The specimens were located in the weld closeout

zone in such a manner that the two dog bones representing each spray unit were located 180 degrees apart. One specimen for each spray unit was tested cryogenically while the remaining specimen was retained as backup.

(c) Post-Process Control: Following completion of spray operations, the foamed subassembly was machined down to drawing mold line tolerance. The cryogenic strain compatibility test specimens were removed and sent to the laboratory for final fabrication and testing. The structure was then subjected to the following series of inspections: visual, nondestructive inspection for void detection and random destructive testing for verification of foam tensile strength and bond line adhesion. Final acceptance was based on the testing of the cryogenic strain compatibility specimens.

(1) Visual Inspection: Following verification of dimensional tolerances, the completed subassembly was inspected in accordance with the following criteria per MA0606-050:

- The foamed material is to be fully cured and free from tack.
- The foamed detail must be free of cracks. (Hairline interfaces resulting from foam roll over adjacent to foam-to-foam joints are acceptable conditions and are not to be classified as defects unless a crack exists.)
- There must be no separation of the foam from attach points or protrusions that extend through the foam.
- There must be no foreign materials in the foamed detail.
- There must be no evidence of incomplete filling of the foamed areas.
- Holes in the trimmed foam surface are not to exceed 1/16 inch in diameter.
- Irregularities in the trimmed foam surface are not to exceed 1/4 inch in any direction in the plane of the foam surface and are not to exceed 1/16 inch in depth.
- There are to be no dents or evidence of foam crushing that reduces the foam thickness more than 10 percent of the nominal dimension from mold line to metal substrate.

(2) Void Detection: The equipment and operational parameters for nondestructive testing by means of the acoustic brush were established by Quality Control Specification MQ0501-035.

The brush assembly consisted of a nylon bristle brush, a microphone for sound pickup, an amplifier, and a set of headphones to be worn by the inspector. The brush was moved across the surface of the foam while the inspector listened to the sound through the headset. A void area would cause a different sonic response from that of a structurally sound area.

(3) Bond Line Adhesion and Tensile Strength: The specific testing was referred to as product quality verification (PQV). The equipment and operational parameters were established by Quality Control Specification MQ0501-034. The principle of PQV testing involved the bonding of a plug of known cross-sectional area to the surface of the structure to be tested. In the case of SOFI, the test area was isolated from the remaining structure by a trepanning operation (a peripheral cut to the substrate). A tensile force was then applied to the plug by a standard hand-operated hydraulic pump. A gauge was incorporated into the system to indicate actual applied load at time of rupture.

3. Threaded Insert Installation (Figure 6.1.4.1-2): The quality assurance aspects of this installation were essentially identical with those imposed on the basic insulation design; see Paragraph 6.1.1.7-b-2.

4. Application of SOFI Top Coats (Figure 6.1.4.1-3): Final finishing of the SOFI system consisted of the application of a polyurethane seal coat followed by application of a white vinyl top coat. The composite coatings were applied in accordance with MA0608-015. Quality assurance provisions consisted of visual inspection for complete coverage and workmanship.

c. Quality Verification of Final Assembly: Final acceptance of the completed stage was accomplished by visual inspection to the requirements previously stated. Final visual inspection was conducted primarily to pick up any accidental damage which may have been incurred during handling of the insulated subassemblies.

6.1.4.8 Repair and Maintenance

Spray-on foam insulation may be repaired by either in-process rework procedures or material review action.

a. In-Process Rework: Process specification MA0606-050 provides procedures for rework of the basic spray-on foam system as follows:

1. Remove and replace discrepant foam material.

2. Abrade thick epoxy amine primer (MB0125-047).

3. Touch up of scratched primer.

4. Reapplication of polyurethane joint resin after 24-hour maximum time to foam has been exceeded.

b. Material Review: Standard repairs to the foam system requiring Material Review Board action are detailed in process specification MA0606-057. The various defects covered include:

1. Repair of cracked moisture barrier coating and foam.

2. Repair of debonded coating.

3. Foam repair with bonded foam block.

4. Foam repair by spray foam application.

5. Foam repair by pour foam application.

6. Temporary repairs.

c. Maintenance: To prevent discoloration due to particulate matter or fungal infestation of the outer coatings of the foam system following extended periods of outdoor exposure, a periodic wash of the insulation with a mild detergent should be performed. Frequency of this procedure depends on results of visual inspection.

6.1.4.9 Reliability

Debonding or breaking away is the only failure mode identified. Results are presented in Table 6.1.4.9-1.

Table 6.1.4.9-1. FMEA-Spray-on Foam

Subsystem or Component	Failure Mode	Mission Effects Remarks
LH_2 Tank Sidewall Insulation	Breaks/Tears Away	Increased boiloff resulting in possibly exceeding vent valve capacity and excess tank pressure. Possible mission abort.

6.1.4.10 Safety

a. Fabrication and Installation: Ventilation must be provided during spray-foaming to reduce the isocyanate that is outgassed below a concentration of 20 parts per million (0.02 ppm). Ventilation also must be provided while sanding or machining foam to reduce foam dust below the explosive limit of 0.025 ounce per cubic foot.

All electrical equipment must comply with California Electrical Safety Orders or National Electric Code for Class II, Division I, environments.

Housekeeping and area cleanliness must receive emphasis to reduce the fire hazard and risk of contamination.

Protective clothing must be worn while spray-foaming. This includes air-line masks, coveralls, gloves, and shoe covers.

Masks approved by the Bureau of Mines for nuisance dusts must be used while sanding or machining foam.

Spray-foaming guns and application equipment are chosen for the capability of consistently proportioning, mixing, and spraying the foam components. Operating personnel will be thoroughly trained in the use of the equipment. Spare parts should be readily available to minimize downtime. Additional safety requirements are given in Paragraph 6.1.1.10.

b. Foam Insulation Use: Low-density foam can be damaged readily by impact. Care should be exercised to prevent damage to the surface when working in the vicinity of foam insulation. When the surface is penetrated, insulation efficiency is reduced and weathering is accelerated. If the penetration is deep enough to approach the tank wall, cryo pumping will lift "divots" of the foam and further reduce insulation efficiency.

   The foam must be inspected after each cryogenic exposure and repairs made to damaged areas.

6.1.4.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing dept. records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost:

   1. 4 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are:

   1. Procurement - 5 weeks.

   2. Subassembly - not applicable.

   3. Installation - 15 weeks.

   4. Checkout - 1 week.

c. Weight: The total as-installed weight is 0.231 lb./ft^2., broken down as follows:

   1. Primer (MB0120-032) - 0.007 lb./ft.^{2}

2. Type II Primer (MB0120-042) - 0.003 lb./ft.^{2}

3. Foam (MB0130-077) 2 lb./ft.^{3} 0.75-inch thick. -0.1253 lb./ft^2

4. Chemseal three coats (MB0135-045) - 0.0720 lb./ft.^{2}

5. Dynatherm (MB0125-046) - 0.0240 lb./ft.^{2}

d. Thermal Performance: The Q of this system is 80 Btu/hr./ft.^{2}. The ρK of this system is 0.065 Btu-lb./hr.-°F-ft.^{4}

6.1.5 Spray-on Foam plus Foam Blankets

6.1.5.1 Description

The spray-on foam plus foam blanket insulation system was used on the S-II stage (S-II-8 and subsequent) in the area of the forward skirt (on S-II-6 and subsequent) and Cylinder 1-bolting ring (V7-531250 and V7-531300). The thermal characteristics of this system are similar to those of the basic spray-on foam described in Paragraph 6.1.4.1.

This configuration was developed for insulating structure with external ribs or stringers. This insulation concept is shown in Figure 6.1.5.1-1. The spray-on foam is applied directly to the primed substrate between the ribs and is machined or sanded flush with the top of the ribs. The components of spray-on foam are described in Paragraph 6.1.4.1.

The foam blanket consists of a prefabricated foam sheet and a prefabricated nylon laminate bonded together to foam a composite. The foam/laminate composite is then bonded to the surface of the foam between the ribs. The butt joints of the blankets are sealed with a gap filler and a wet layup.

The outer surface of the foam blanket is then coated as described in Paragraph 6.1.4.1.

6.1.5.2 Application

a. Utilization: The spray foam plus foam blanket system can be utilized in any application involving complex structural geometry and requiring the same thermal and structural characteristics as the spray foam system described in Paragraph 6.1.4.2.

b. Performance Characteristics: This system has been used successfully on eight S-II flight stages. In combination with the spray foam system, it has provided more than the required degree of thermal protection to the stage structure and LH_2.

c. System Limitations: The system has the same limitations as the spray foam system. It is limited to temperatures of 600 F when under the S-II type boost environment. For temperatures in excess of 600 F, the foam system must be protected.

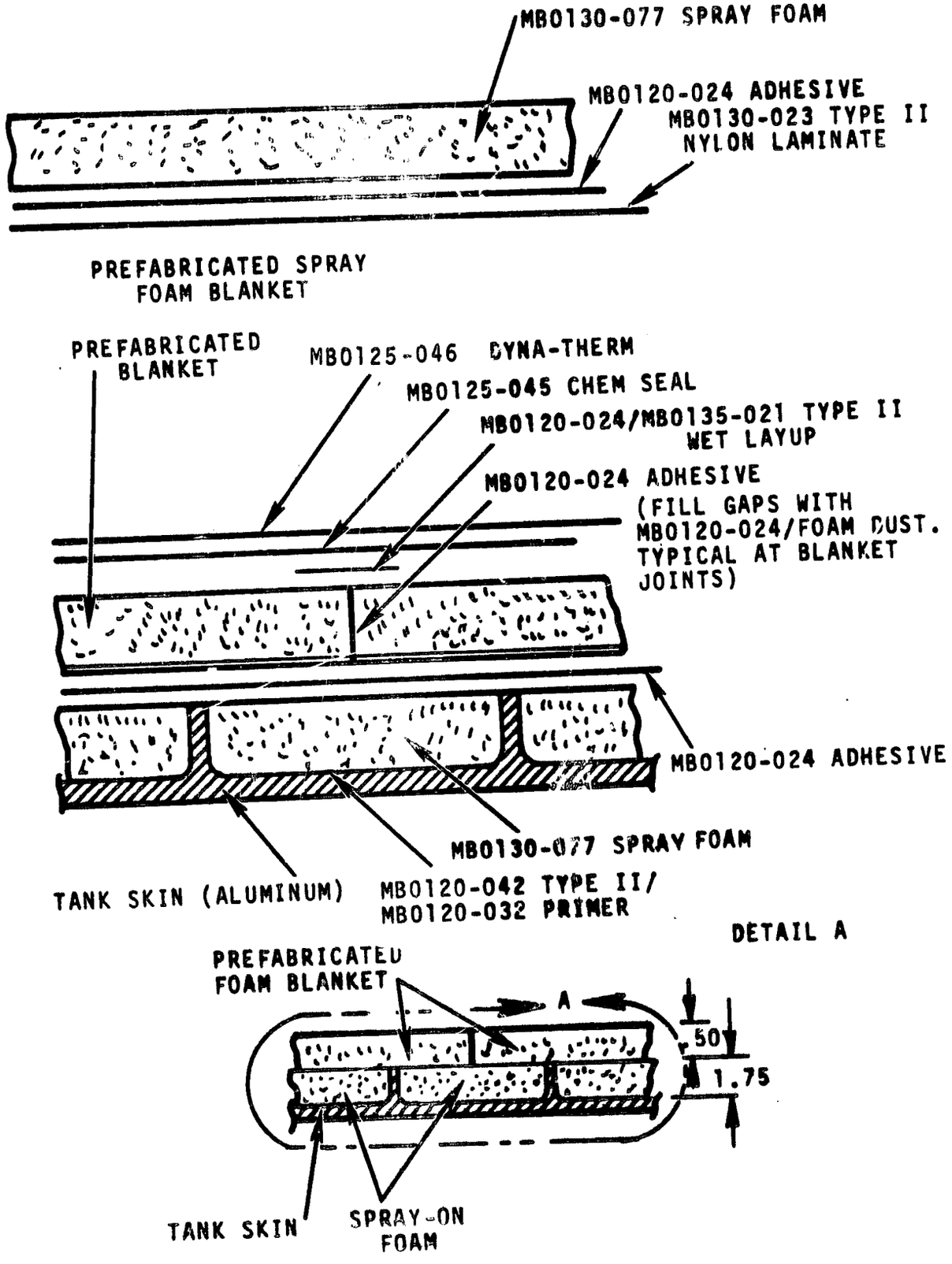


Figure 6.1.5.1-1. Spray-on Foam Plus Foam Blankets

d. Design Problems: Design problems associated with this system are the same as those covered in Paragraph 6.1.4.2. In addition, voids may occur in the bondline between the foam blocks and outer blanket due to air entrapment during bonding. Careful bondline thickness control was exercised and steps were inserted in the assembly procedure to insure that air is worked out before vacuum bonding is started.

e. Verification: Materials, processing, and design verification for this system were the same as that described for the spray foam system. Additional tests were conducted successfully on panels where the foam system was exposed to cryogenic cycling, aeroheating, and vibration.

6.1.5.3 Thermal Performance

The thermal performance characteristics of this insulation system were determined assuming that this system was applied to a structural skirt protruding from a tank containing LOX which is subjected to both ground-hold and launch environments. The KSC hot day, ground-hold environment assumed is defined in Paragraph 4.1.1.2. This launch environment used is the maximum aerodynamic heating trajectory for the LOR mission shown in Figure 4.2.2.3-1. The thermal characteristics presented here apply to a unit area of the basic insulation.

The effective insulation system thermal conductivity as a function of temperature and thermally averaged thickness value is presented in Figure 6.1.4.3-1. Using these average K values, the predicted ground-hold heat flux was found to be approximately 140 Btu/hr.-ft.^{2} and the predicted total accumulated heat leak to LOX is 41 Btu/ft.^{2} for the assumed S-II mission profile. A detailed analysis of the thermal performance characteristics is presented in Paragraph 7.3.1.5.

6.1.5.4 Structural Performance

The discussion of the structural performance characteristics of the spray foam insulation system given in Paragraph 6.1.4.4 also applies to this insulation system. The addition of prefabricated blankets (spray foam plus nylon laminate) to the insulation system requires that more materials and more layers remain strain compatible with the tank deflections and strain rates.

6.1.5.5 Materials and Processes

a. Materials:

1. Foam: Two-component, flame-retardant polyurethane foam, two-pound density, for spray application (MB0130-077).

2. Adhesive Resin: Polyurethane, two-component, low-temperature curing (MB0120-024).

3. Primer: Epoxy amine corrosion preventive primer, two-component, room-temperature curing (MB0125-047).

4. Nylon Fabric: Phenolic resin preimpregnated nylon fabric for laminate fabrication (MB0130-023 Type II).

5. Exterior Coatings:

   (a) Elastomeric polyurethane base coating material, two-component, (MB0125-045).

   (b) Vinyl color-coat material, single component (MB0125-046).

b. Process:

1. Spray Foam: Spray foam insulation (MB0130-077) is applied to the ribbed surface detailed in Figure 6.1.5.1-1 per MA0606-050. The basic processing requirements are as specified in Paragraph 6.1.4.5. Because of the irregular surface being insulated, special care must be taken to avoid foam liftoff or void entrapment. Assurance that foam is sprayed into the corners at the base of the stringers will usually provide acceptable insulation. Following spray application and cure, the foam is machined flush with the tops of the stringers.

2. Blanket Fabrication:

   (a) Prefabricated Foam Block: Foam blocks are fabricated per the applicable processing requirements of MA0606-050. The open mold surfaces are treated with a nonsilicone release system. The foam blocks are trimmed with cutting tools to the approximate dimensions and hand-sanded to final dimensions.

   (b) Nylon/Phenolic Laminate: A nylon fabric phenolic preimpregnated material (MB0130-023 Type II) is laminated per MA0605-003. A two-ply layup is single-stage-cured under vacuum at 340 F for 90 to 120 minutes.

   (c) Assembly: Using polyurethane resin (MB0120-024), the foam block is bonded to the precured laminate per MA0605-014 Method III. Twenty-five grams per square foot of resin (approximately 0.010-inch thick) is applied to both faying surfaces. The assembled blanket is cured for 168 hours, the first 24 hours of which is under vacuum.

3. Blanket Bonding: Bare aluminum exposed on the stringer tops following machining is primed with epoxy amine primer (MB0125-047) in accordance with the requirements of MA0606-050. The foam/laminate blanket is then bonded to the structure per MA0605-014 Method III. Extreme care must be exercised to avoid air entrapment as the foam blanket is mated to the structure.

4. Joints: All gaps between adjacent foam blankets are filled with MB0120-024 polyurethane resin mixed with foam dust per MA0606-050, in-process rework Method III. A thixotropic paste (6 to 10 parts by

weight foam dust with 100 parts resin) is inserted in the gaps. The subsequent laminate application over the joint may proceed immediately after the thixotropic paste is inserted in accordance with the requirements of MA0605-014 Method I or II.

5. Protective Coatings: The insulation blanket must be protected from weather, fungus, and di loration by application of three coats of polyurethane coating (MB0125-045) and one coat of vinyl color coat (MB0125-046) per MA0608-015.

6.1.5.6 Manufacturing

a. Description: The spray-on foam insulation is applied in the same manner as that described in Paragraph 6.1.4.6. The foam was sprayed into the cavities of the ribbed side walls and machined flush with the tops of the standing ribs. Prefabricated foam/nylon fabric composite panels were bonded over the areas of the rib sections. This design was established because it was impossible to spray in one application the cavity and over the ribs simultaneously without large void areas directly over the ribs.

The foam blankets were fabricated and installed in the following manner. A 4- to 6-inch high foam bun was sprayed onto a honeycomb sandwich platen slightly larger than the foam panel net size. The foamed billet was band-sawed into net thickness sheets, then trimmed to oversize to make the foam panel. A two-ply nylon laminate panel was fabricated using the vacuum bag and hot bonding oven process. This nylon laminate was then trimmed and bonded to the foam panel using a liquid room-temperature curing adhesive and vacuum bag pressure system to make a foam blanket.

The foam blanket installation consisted of trimming and prefitting the blankets to fit the previously machined cavity of the stage sidewall. The blankets were bonded in place using the room-temperature curing liquid adhesive and vacuum bag pressure.

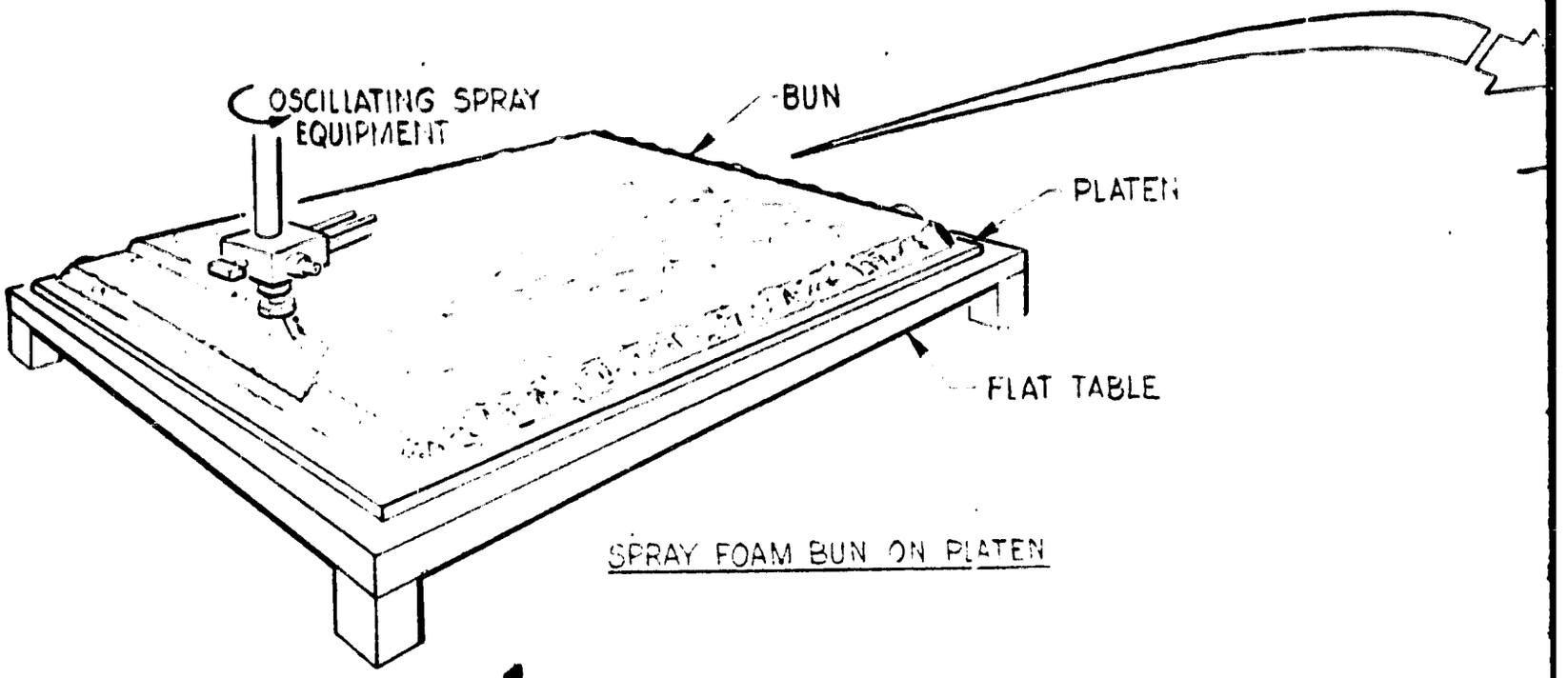
After the blankets were bonded and cured, they were hand-sanded flush with the adjacent surfaces. The joint seams were filled with a mixture of adhesive and foam dust and covered with an adhesive wet nylon strip to prevent air leakage between the basic foam and the blanket. After cure of the splice joints, the entire blanket surface was sanded, vacuum cleaned, and blemishes were filled in preparation for the final coating. A moisture barrier and color coat was applied using a common paint roller as previously described in Paragraph 6.1.4.6. For the foam blanket fabrication and installation sequences, see Figure 6.1.5.6-1.

b. Tooling and Equipment:

1. Spray foam gun equipment (Model #510 Lemco).

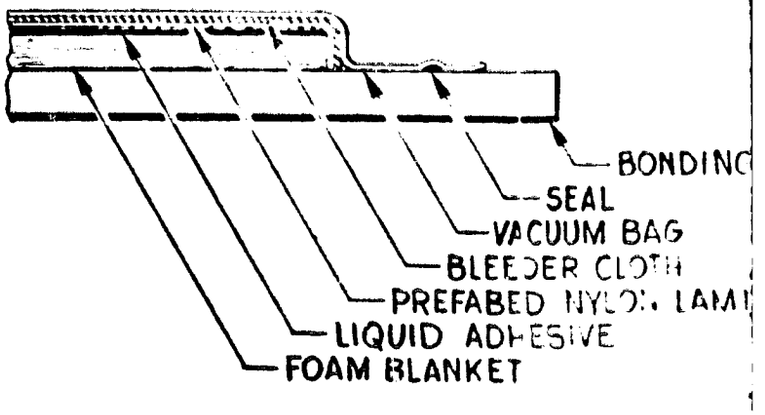
2. Spray platens for spray foam bun.

3. Bonding platen for nylon laminate layup and bond.



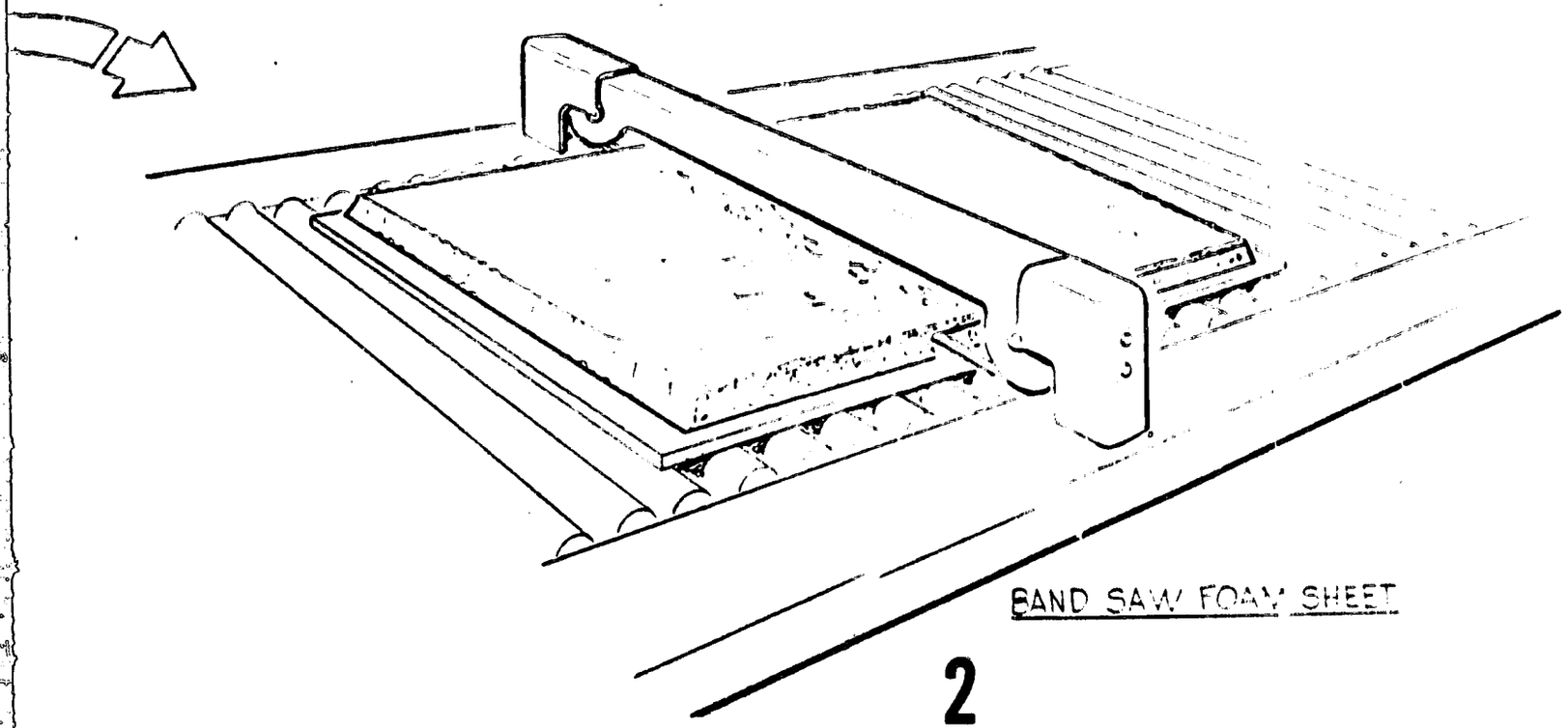
SPRAY FOAM BUN ON PLATEN

1



SECTION A-A

FOLDOUT FRAME 1



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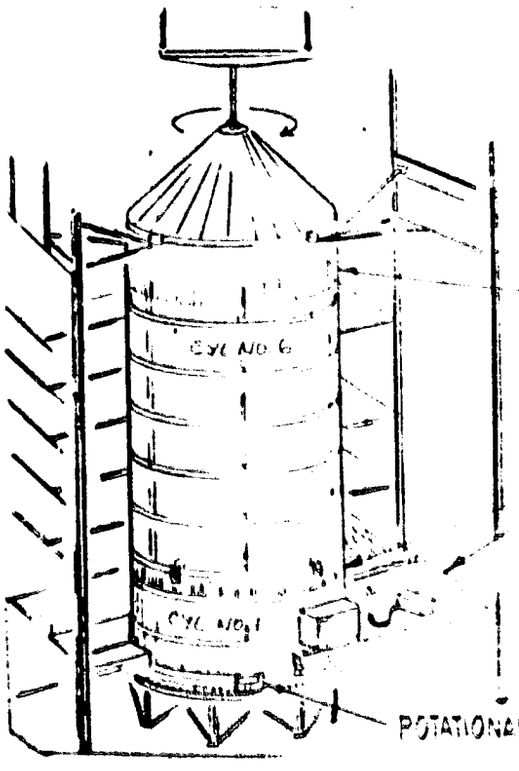
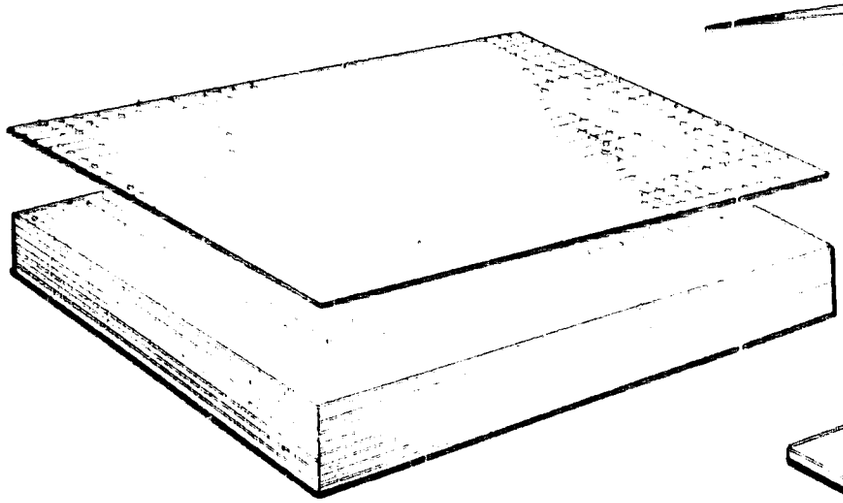


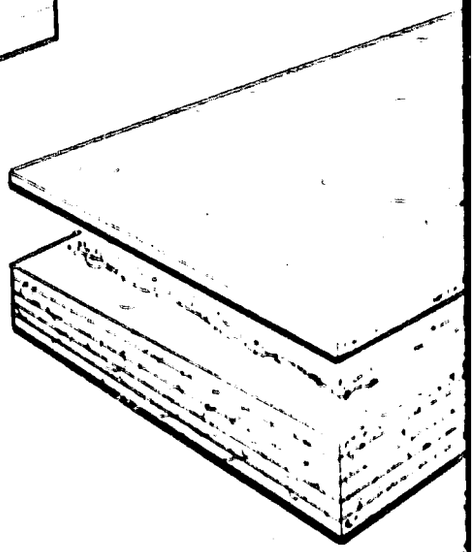
- BONDING TABLE
L
M BAG
CLOTH
LOY LAMINATE
E

5

FOLDOUT FRAME 2



PREFAB NYLON LAMINATE



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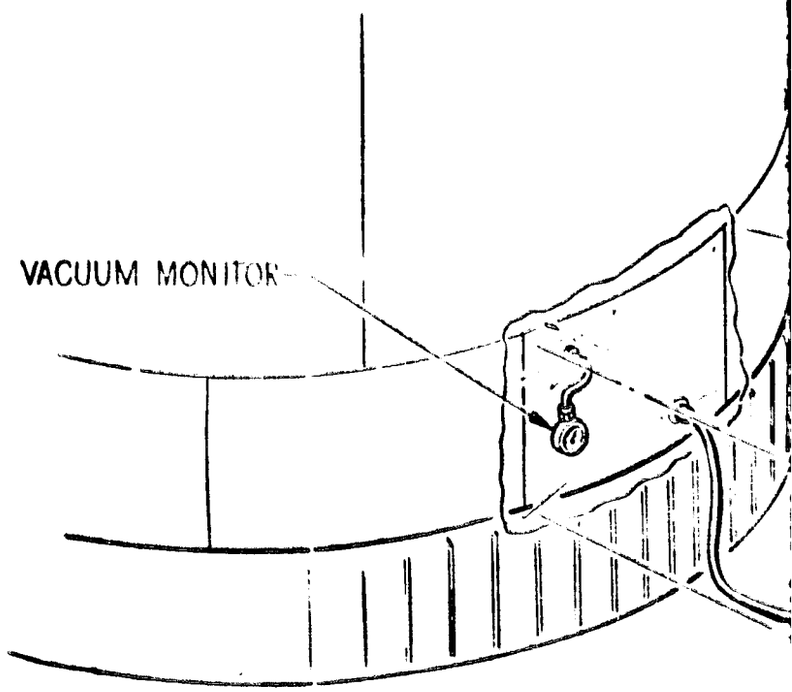


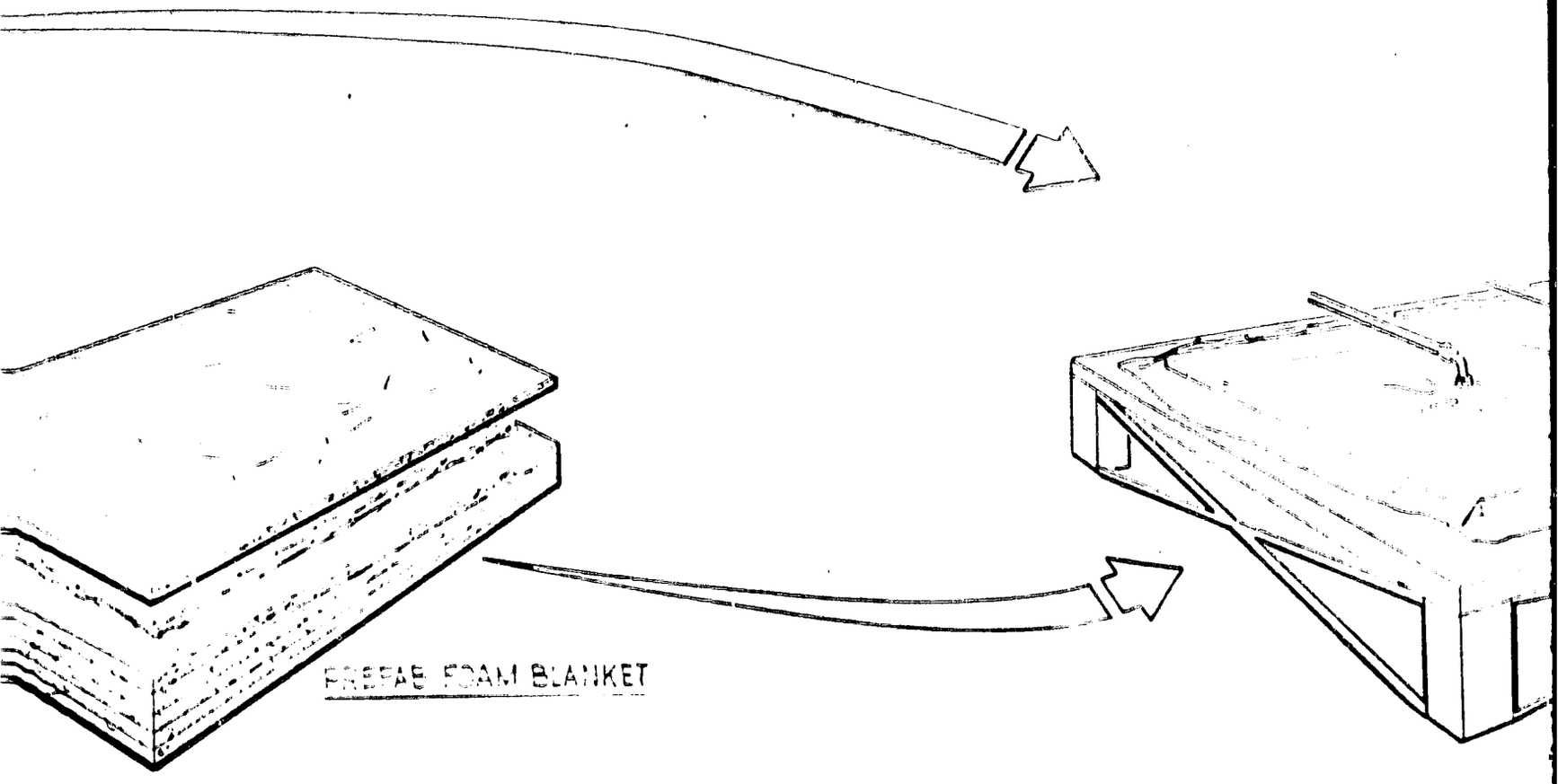
PD SKIRT INSULATION

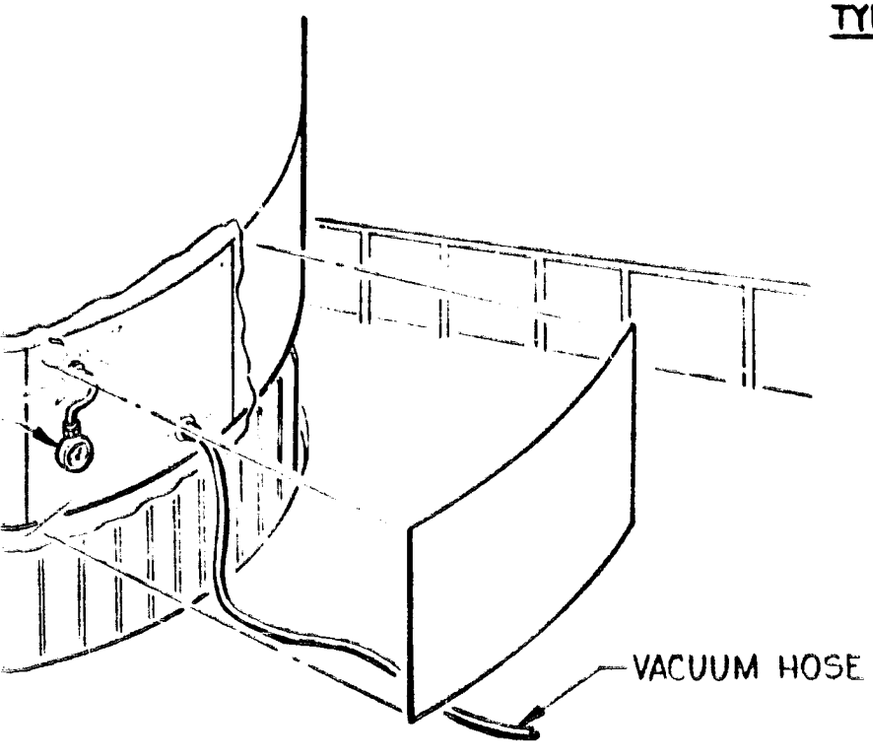
NDER NO. 1 & BOLTING RING INSULATION
PLATFORM

6

VACUUM BOND PANELS TO STAGE

FOLDOUT FRAME 3





TYPICAL OPERATIONS

- APPLY ADHESIVES
- INSTALL BLANKET
- VACUUM BAG & CURE
- FILL JOINTS (ADHESIVE & FOAM DUST)
- APPLY WET LAYUP OVER JOINTS
- SAND SMOOTH & APPLY MOISTURE BARR

Figure 6.1.5.6

NELS TO STAGE

FOLDOUT FRAME 4

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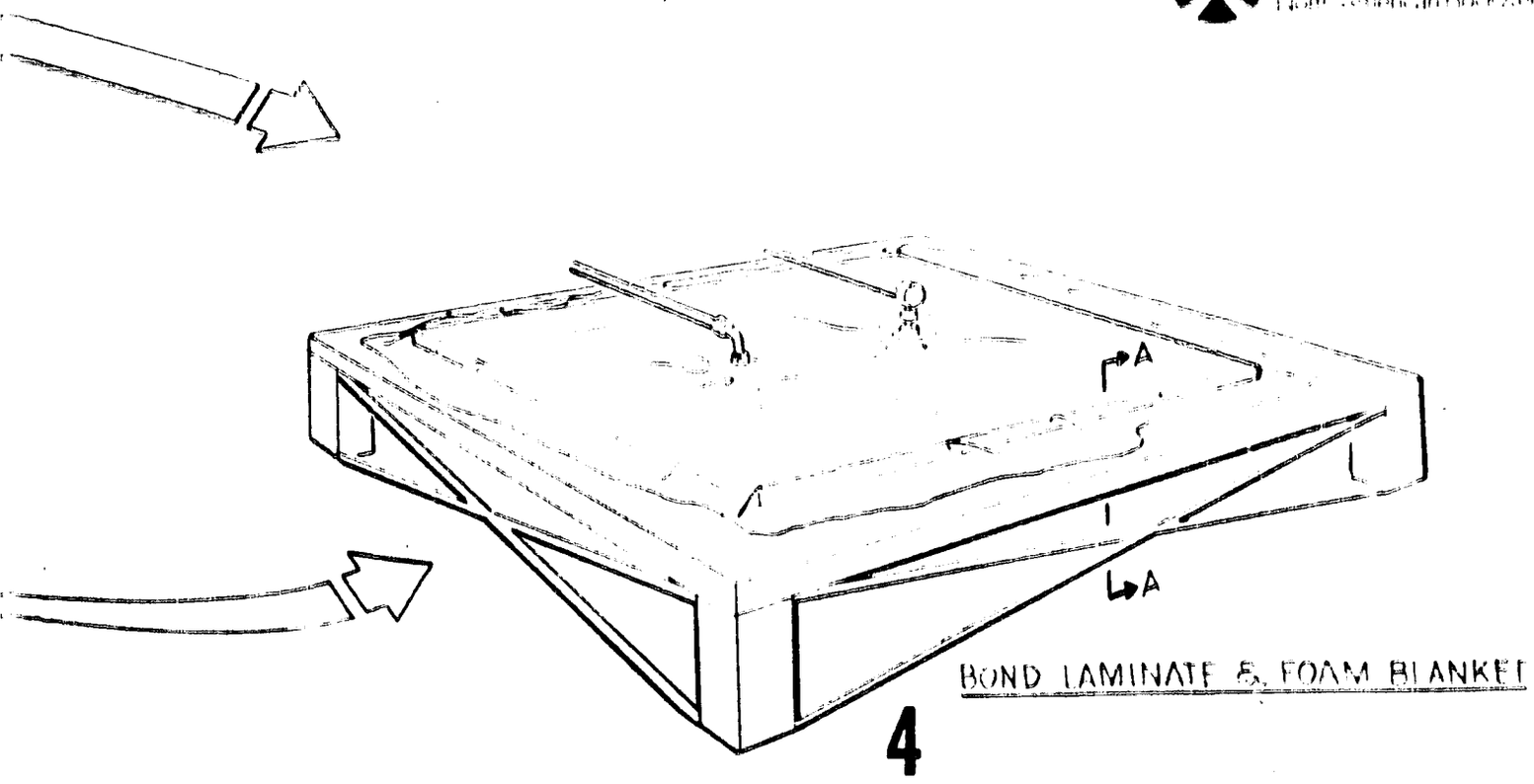


ICAL OPERATIONS

- APPLY ADHESIVES
- INSTALL BLANKET
- VACUUM BAG & CURE
- FILL JOINTS (ADHESIVE & FOAM DUST)
- APPLY WET LAYUP OVER JOINTS
- SAND SMOOTH & APPLY MOISTURE BARRIER

Figure 6.1.5.6-1. Spray-On Foam Plus Foam Blanket

4. Horizontal band sawing tool to cut foam sheets.

5. Tooling and equipment for basic spray foam system described in Paragraph 6.1.4.6.

6.1.5.7 Quality Assurance

The Quality Assurance provisions for this design were essentially the same as those defined in Paragraph 6.1.4.7 for the basic SOFI design. Identical controls were invoked during the fabrication of the foam blanket details as for other foamed subassemblies except that cryogenic strain compatibility test specimens were not required during fabrication of hardware employing the foam blanket as the external insulation layer. This was primarily because the relatively low mission strain levels encountered in the bolting ring/cylinder No. 1 and forward skirt where the foam blanket was employed. Two production operations were performed on the foam blankets which were not common to the basic SOFI system described in Paragraph 6.1.4.7. These were fabrication of the foam blanket nylon laminate and bonding of the foam blanket to the tank structure.

a. Laminate Fabrication (MA0605-003): Following cure of the MB0130-023 preimpregnated nylon laminate, test samples were removed from the excess laminate material and tested as follows:

   1. Tensile strength was determined per Federal Test Method 406, Method 1001.

   2. Flatwise tensile strength was determined per MIL-A-25463.

b. Blanket Bonding (MA0605-014): Routine inspection for surface preparation, adhesive mix, and proper cure conditions was conducted. No process verification coupons were fabricated during the production bonding operation. Extreme care was exercised to avoid trapped air in the bond line during layup of the blanket composites on the structure.

6.1.5.8 Repair and Maintenance

Repair and maintenance of spray foam insulation is as specified in Paragraph 6.1.4.8. Repair or rework of the bonded insulation system requires Material Review Board approval.

6.1.5.9 Reliability

Debonding or breaking away is the only failure mode identified. Results are presented in Table 6.1.5.9-1.

6.1.5.10 Safety

Safety requirements for this insulation system are detailed in Paragraphs 6.1.4.10 and 6.1.6.10.

Table 6.1.5.9-1. FMEA-Spray-on Foam Plus Foam Blankets

Subsystem or Component	Failure Mode	Mission Effects Remarks
Forward Skirt and Cycle #1 Spray-On Foam	Breaks/ Tears Away	Heat transfer rate increases. Increased propellant topping required. Possible mission scrub.

6.1.5.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 27 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 5 weeks.

Subassembly - Data not available.

Installation - Data not available.

Checkout - Data not available.

c. Weight: The total as-installed weight is 0.656 lb/ft^2 broken down as follows:

1. Dynatherm (MB0125-046) - 0.0240 lb/ft^2
2. Chemseal (MB0125-046) - 0.0720 lb/ft^2
3. Foam 0.50-inch thick (MB0130-077) - 0.0835 lb/ft^2
4. Adhesive (MB0120-024) - 0.0600 lb/ft^2
5. Type II nylon laminate (MB0130-023) - 0.0546 lb/ft^2
6. Adhesive (MB0120-024) - 0.0600 lb/ft^2
7. Foam 1.75-inch thick (MB0130-077) - 0.2923 lb/ft^2
8. Type II primer (MB0120-042) - 0.0030 lb/ft^2
9. Primer (MB0120-032) - 0.0070 lb/ft^2

d. Thermal Performance: The Q of this system is 140 Btu/hr/ft^2. The ρK of this system is 0.064 Btu/lb/hr-^{0}F-ft^4.

6.1.6 Pour Foam

6.1.6.1 Description

The principal application of pour foam insulation on S-II stages has been in areas of foam closeouts and field repairs. The pour foam material closely matches the spray foam thermal characteristics. Therefore, from thermal insulation performance requirements, the pour foam can be used interchangeably with the spray foam.

For typical pour foam insulated components see Figure 6.1.6.1-1 and installation drawing (V7-531237).

6.1.6.2 Application

a. Utilization: Pour foam has the same general thermal and structural characteristics as spray foam; therefore, it can be utilized in association with spray foam for repairs or in areas that are difficult to spray. It is used as insulation for pipes, storage tanks, and generally for any application requiring this degree of protection.

b. Performance: Pour foam has been used successfully on 12 S-II stages. Its performance is described as part of the total spray foam insulation system in Paragraph 6.1.4.2.

c. Limitations: The system limitations are the same as those described for spray foam in Paragraph 6.1.4.2.

d. Design Problems: The problems are unique for the pour foam because of its limited usage. Principal problems are given in Table 6.1.6.2-1.

e. Verification Testing: The pour foam was considered verified as the result of the program described in Paragraph 6.1.4.2. Applicability of pour foam was demonstrated on a large-scale tank, on flight vehicles, and on small panel tests (SID 63-600-9).

6.1.6.3 Thermal Performance

An important performance characteristic of pour foam insulation is to prevent heat leaks in areas on the S-II where the spray foam insulation is in need of repair or is not applicable to the design, such as around vent and recirculation flanges. The thermal and physical properties are the same as those of the spray foam. Therefore, thermal performance of pour foam will be the same as for spray foam (see Paragraph 6.1.4.3).

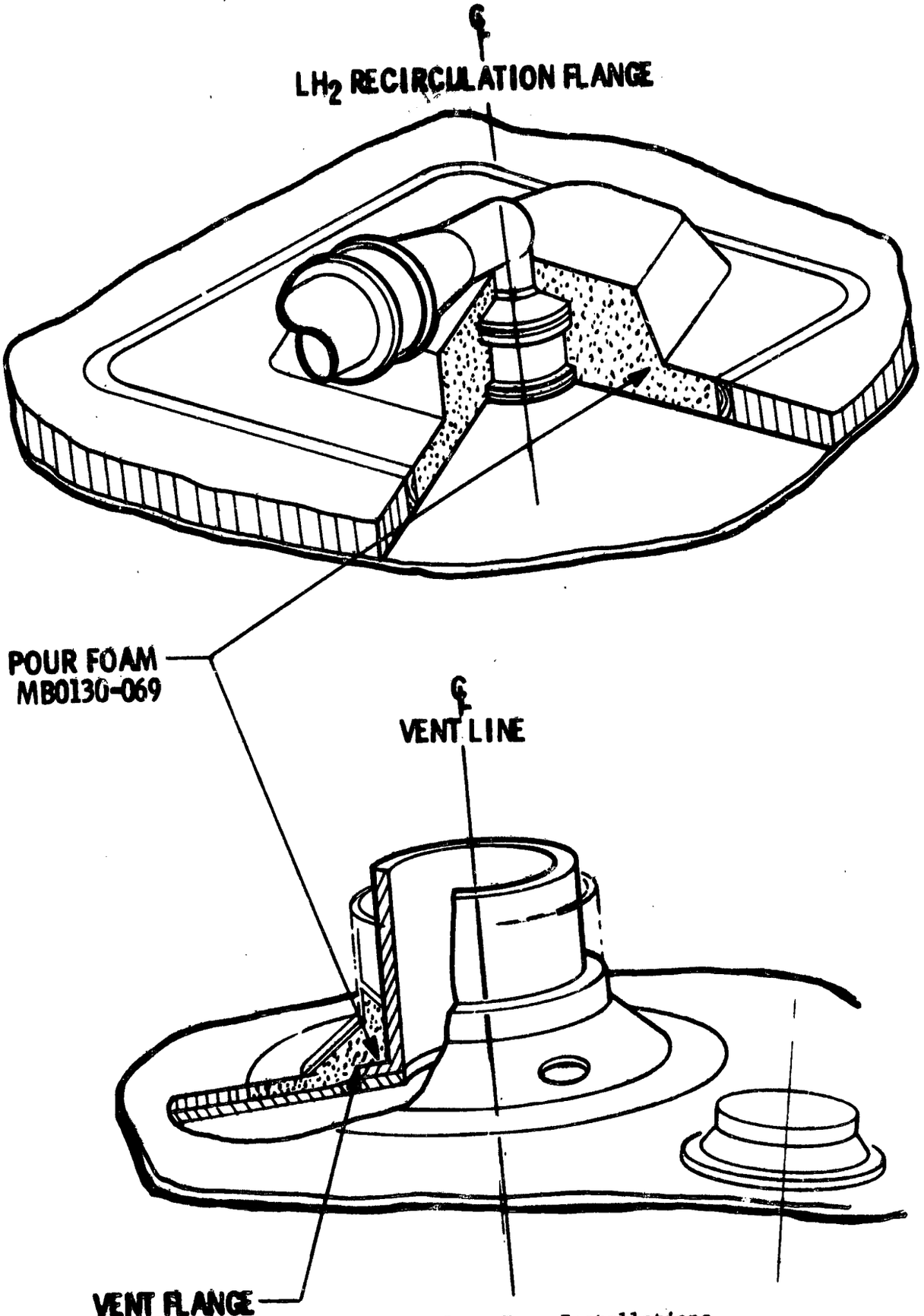


Figure 6.1.6.1-1. Pour Foam Installations

Table 6.1.6.2-1. Pour Foam Problems and Solutions

Problems	Solutions
Absorption of water in foam	Provide better processing to achieve proper mixture ratio
Corrosion under foam around feedline elbows	1. Use with proper primer system 2. Observe masking and cleaning procedures
Cracking of foam around elbows: Non-uniformity Higher density	1. Use pour foam of proper density and structural flexibility 2. Conduct pouring operations only under acceptable environment (humidity and temperature) 3. Match foam with heat absorption capacity of metal substrate
Foam debonds on detanking	1. Improve processing to minimizing leak paths through foam 2. Repair as required

6.1.6.4 Structural Performance

The structural performance characteristics of the pour foam insulation system are identical to those described for the spray foam insulation given in Paragraph 6.1.4.4. In addition, the pour foam is normally applied near closeouts and discontinuities as shown in Figure 6.1.6.1-1. These discontinuity stresses and strains must be considered in addition to the loadings given in Paragraph 6.1.4.4.

6.1.6.5 Materials and Processes

a. Materials:

1. Foam: Polyurethane, two-component, three-pound density, foam-in-place material (MB0130-069).

2. Primer: Polyester/isocyanate, two-component, room-temperature curing (MB0120-042 Type II).

3. Adhesive Resin: Polyurethane, two-component, room-temperature curing (MB0120-024).

b. Process: Pour foam is applied in accordance with the requirements of MA0106-065.

1. Material Storage and Handling: All materials are stored and handled in accordance with their material specifications.

2. Surface Preparation: Tank wall faying surfaces, having previously been primed with adhesive primer (MB0120-032), are primed with polyester primer (MB0120-042 Type II) per MA0606-050. This requirement is specified on the engineering drawing.

3. Molds: To provide containment for rising pour foam insulation, closed molds are assembled from suitable materials. A closed mold is constructed so that the mixed component materials are poured into an opening provided at or near the top and the opening secured in position as the foam approaches. Blow holes are provided to allow escape of trapped air and result in complete filling of the mold. Mold surfaces designated as release surfaces are fabricated of conventional materials coated with a non-volatile release agent such as high melting point paraffin, wax, polyvinyl acetate, polytetrafluoroethylene spray, fused polyethylene, or polyethylene tape.

   To meet the apparent density requirement of the specification (3.0 ± 3 pounds per cubic foot) all mold surfaces should be heated to 110 ± 10 F prior to pouring the mixed material into the mold.

4. Material Calculations: The amount of component materials required to fabricate a given part is calculated as follows:

$$W = Wa + Wb = V \times D \times C;\ Wa = W\ (Ra/100)$$

W = Total weight of material, lb.

Wa = Weight of Component A, lb.

Wb = Weight of Component B, lb.

V = Volume of cavity or mold, ft^2.

D = Density of lb/ft^3.

C = Overage (allowance factor for material remaining in the mixing container)

Ra = Parts by weight ratio of Component A specified on material container

5. Mixing and Delivery: The pour foam components are hand-mixed using propeller-type equipment. The maximum mix time prior to pouring is 25 seconds. Mixing must extend to the edges of the container to insure complete mixing.

Environmental controls required in the working area during foam mixing and delivery are a temperature 65 to 90 F and a maximum relative humidity of 70 percent.

The mixed material is poured into the mold prior to the initiation of foaming as indicated by creaming of the material.

Multiple pours may be made to fill a mold cavity completely. The material must be cured until it is rigid to the touch and the surface temperature is less than 120 F. A thin coat of freshly mixed material may be painted over the previously cured foam surfaces immediately prior to making a subsequent pour.

6. Cure: The foam assembly must be allowed to cure a minimum of 24 hours at 60 to 80 F prior to removal of the mold and subsequent coating applications.

7. Protective Coating: A wet layup of polyurethane resin (MB0120-024) and nylon cloth is applied to the cured foam insulation in accordance with MA0605-014.

6.1.6.6 Manufacturing

a. Description: The S-II forward bulkhead vent lines and flanges necessitated insulation to conform with the existing forward bulkhead spray foam insulation. This was accomplished using the pour foam method.

A circular cavity was formed by trimming the existing spray foam around the vent lines. All metal surfaces exposed were abrasively cleaned and solvent-wiped. A "Z" seal wet layup was installed around the cavity to insure that all exposed spray foam was properly sealed off. Koropon primer was applied to the bare aluminum surfaces within the periphery of the cavity. Tank surfaces having M602 primer were primed with primer M.

The "Z" seal was covered with aluminum tape on the top side spray foam area only. A pour foam tool was then positioned in place over the cavity and taped securely to accept the pour foam.

Pour foam materials were mixed and poured into the cavity through the existing pour foam holes in the mold. After cure, the mold was removed and the foam trimmed to the required configuration. A nylon fabric polyurethane resin wet layup was then installed over the foamed surface.

The pour foam fabrication and installation sequence is shown in Figure 6.1.6.6-1.

b. Tools and Equipment: Tools used were simple aluminum containment type to keep the pour foam in a definite area. Equipment consisted of plastic knives, two-quart mixing buckets, mechanical mixers, stop watches, gram weighing scales, adhesive tapes, and miscellaneous shop aids.

6.1.6.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0106-065): Subassembly process control consisted of those steps necessary to assure the foam material was applied in a properly prepared cavity (mold), in the proper ratio and amount, and under the required environmental conditions.

1. Molds: Molds were allowed to be either open or closed types; however, even the closed-mold method of processing required the cavity be prepared so that trapped air would escape during the foaming reaction. In order to assure a nominal 3 lb/ft^3 foam detail, the molds were verified to be at 110 ± 10 F prior to pouring the mixed material into the mold.

2. Ratio and Mold Volume Verification: To further assure proper end product density and complete fill, the mold cavity volume was calculated and the amount of foam (plus 10 to 15 percent) required for a complete fill at a 3 lb/ft^3 density was determined and verified.

3. Environmental Control: The temperature of the working area was verified to be between 65 and 90 F, with a relative humidity of 70 percent or less. It was further verified that the temperature of the two foam components was between 63 and 73 F immediately prior to mixing.

c. Quality Verification of Final Assembly:

1. Visual Inspection: Following final machining operations, the foam was inspected to the following criteria:

(a) The foam was fully cured and free from tack.

(b) There were no cracks in the foamed detail.

(c) There was no separation of the foam from attach points or protrusions that extended through the foam.

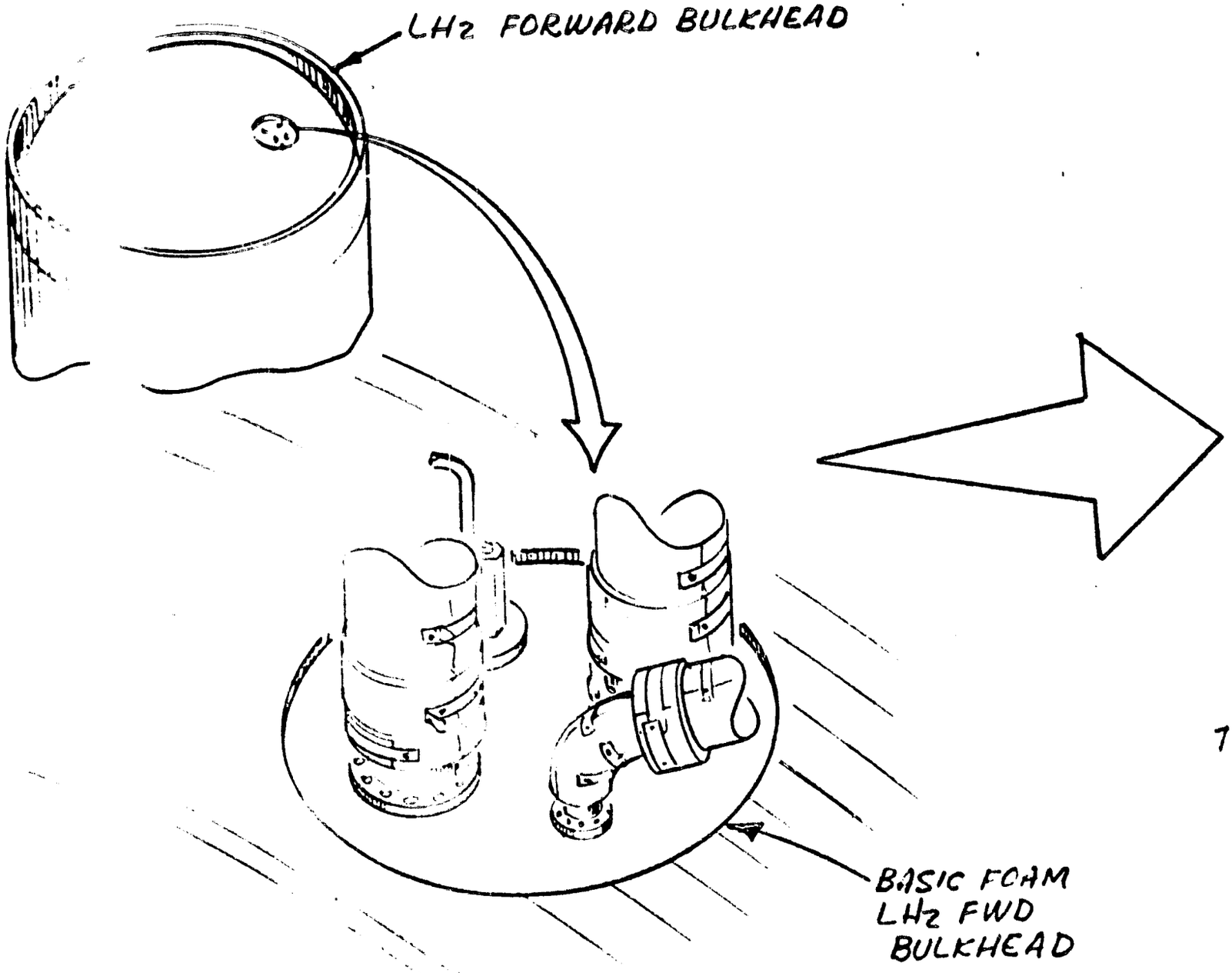
(d) There were no foreign materials in the foamed detail.

(e) There was no evidence of incomplete filling.

(f) Holes in the machined surface did not exceed 1/16 inch in diameter.

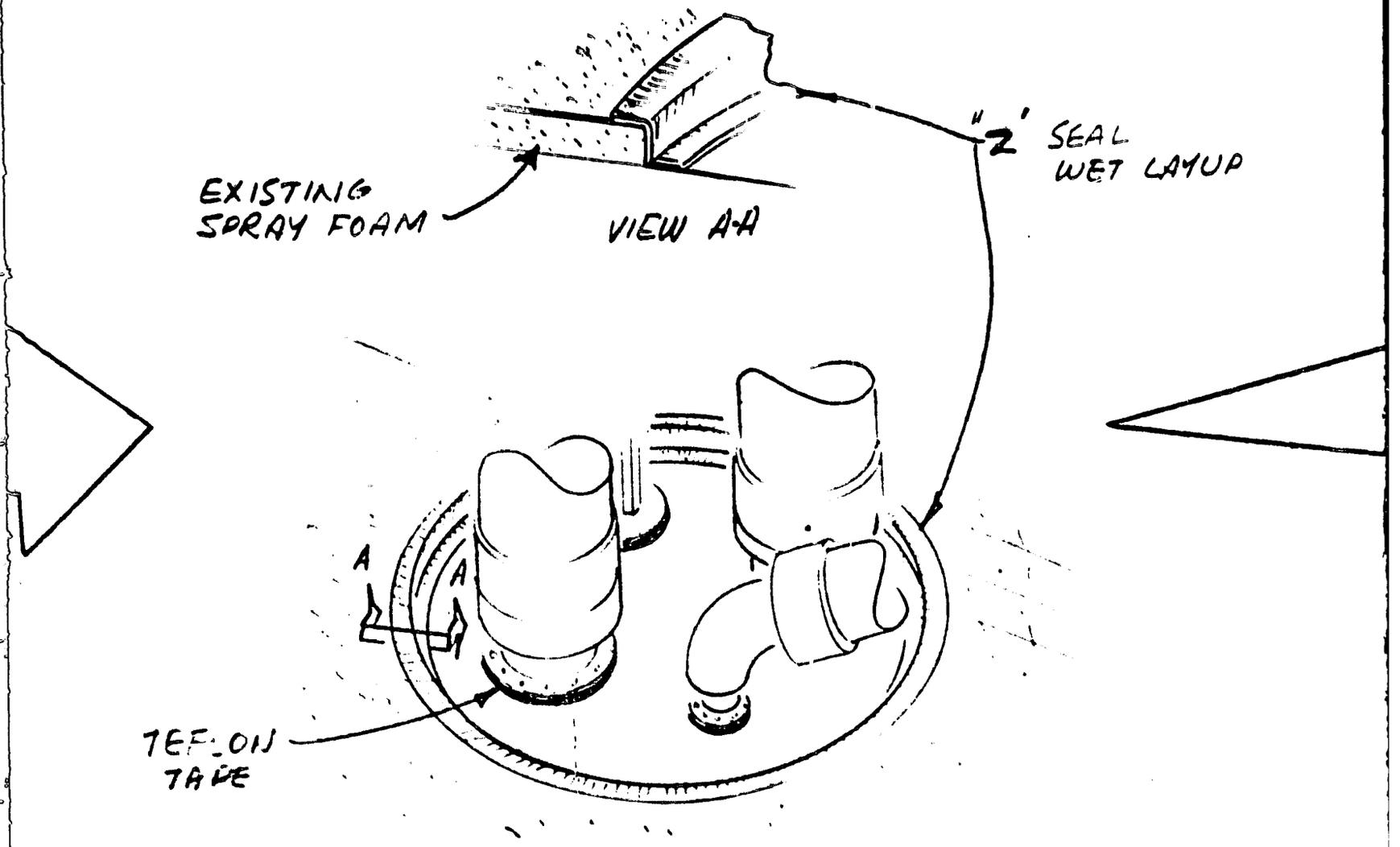
(g) Irregularities in the trimmed foam surface did not exceed 1/4 inch in any direction and did not exceed 1/16 inch in depth.

(h) There were no dents or evidence of crushing of the foam.



- BASIC INSULATION (SPRAY FOAM) WAS CLEANED METAL AREAS WERE CLEANED AND SOLVENT WIPED WITH MEK

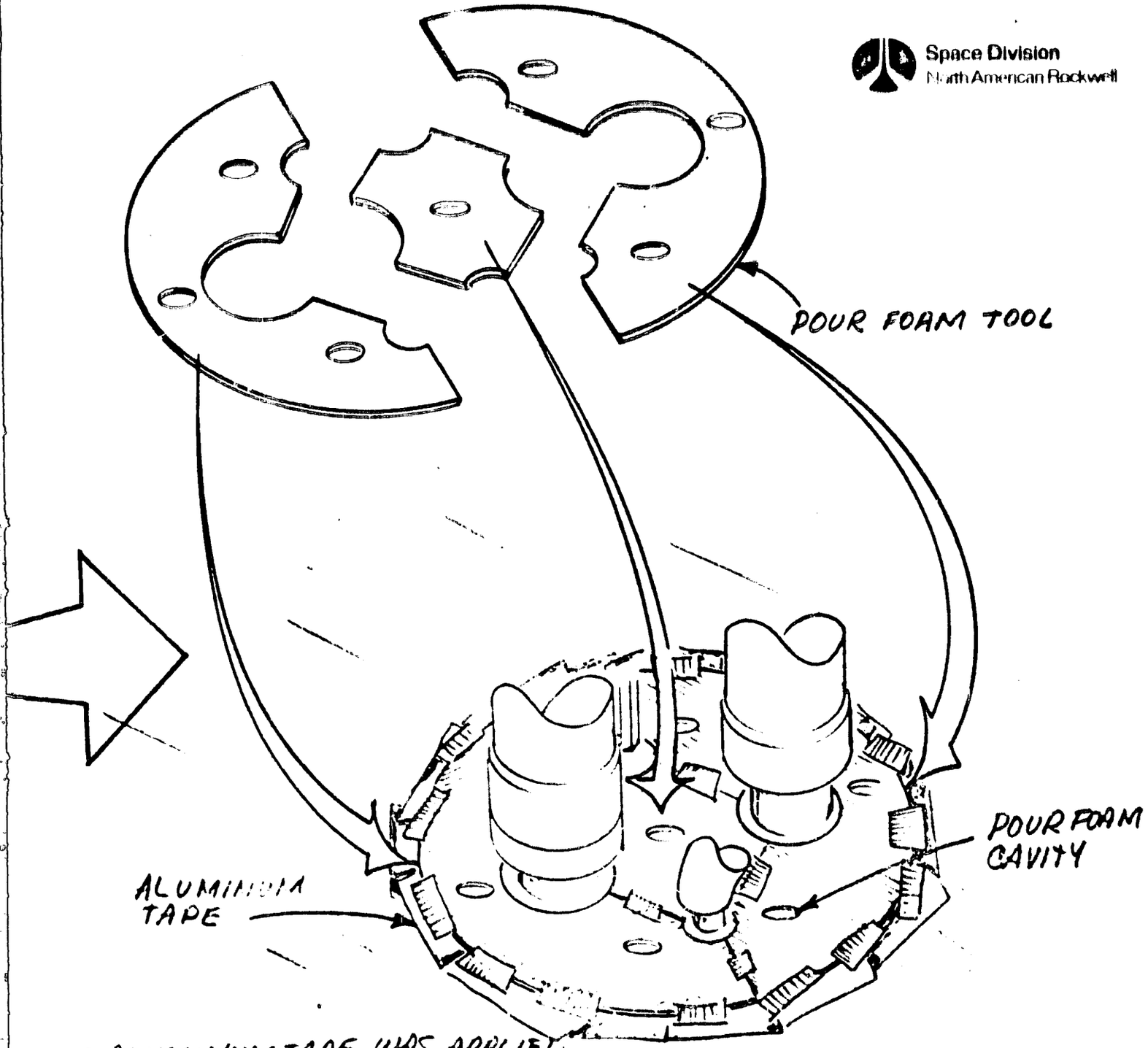
FOLDOUT FRAME



- A "Z" SEAL WET LAYUP WAS INSTALLED AT THE SURFACE OF EXISTING INSULATION
- KOROPON PRIMER WAS APPLIED TO ANY BARE ALUM. SURFACES AROUND PERIPHERY OF THE VENT LINE FLANGES

FOLDOUT FRAME 2

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



- ALUMINUM TAPE WAS APPLIED OVER 2" SEAL LAYUP AND EXISTING SPRAY FOAM
- POUR FOAM TOOL WAS POSITIONED OVER CAVITY AND TAPED DOWN
- THE FOAM WAS POURED PER SPECIFICATIONS

Figure 6.1.6.6-1. Pour Foam

2. Field Visual Inspection: The above visual inspection constituted final acceptance of the foamed detail during production operations. However, all pour foamed details were again inspected visually subsequent to the initial cryogenics detanking at the Mississippi Test Facility where each vehicle underwent captive full duration firing.

6.1.6.8 Repair and Maintenance

a. Repair: No standard repair procedures were developed.

b. Maintenance: No special maintenance of this area is required; however, inspection following cryogenic tankage is recommended for detection of insulation debond.

6.1.6.9 Reliability

No detailed failure mode effects analysis was formulated because there are no obvious first-order failure modes.

6.1.6.10 Safety

a. Fabrication and Installation: Ventilation should be provided during pour-foaming to reduce the isocyanate that is outgassed below a concentration of 20 parts per million (0.02 ppm). Ventilation also should be provided while sanding or machining foam to reduce foam dust below the explosive limit of 0.025 ounce per cubic foot.

All electrical equipment must comply with California Electrical Safety Orders or National Electric Code for Class II, Division I, environments.

Housekeeping and area cleanliness should receive particular emphasis to reduce the fire hazard and risk of contamination. Protective clothing must be worn while mixing and pouring foam. This clothing includes cover-all, gloves, and shoe covers. Masks approved by the Bureau of Mines for nuisance dusts must be used while sanding or machining pour-foam.

If mechanical equipment is used to mix pour foam it must be chosen for the capability of consistently proportioning and mixing the foam components. Operating personnel will be thoroughly trained in the use of the equipment. Spare parts should be readily available to minimize down time.

Additional safety requirements are given in Paragraph 6.1.1.10.

b. Pour-Foam Use: Low-density foam can be readily damaged by impact. Care should be exercised to prevent damage to the surface when working in the vicinity of foam insulation. When the surface is penetrated, insulation efficiency is reduced and weathering is accelerated. If the penetration is deep enough to approach the tank wall cryo pumping will lift "divots" of the foam and further reduce insulation efficiency.

The foam must be inspected after each cryogenic exposure and repairs made to damaged areas.

6.1.6.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: Data not available.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 5 weeks.

Subassembly - Not applicable.

Installation - 6 weeks.

Checkout - Not applicable.

c. Weight: The total as-installed weight is 0.325 lb/ft^2 broken down as follows:

1. Foam (1.0-inch thick) - 0.250 lb/ft^2

2. Wet layup - 0.075 lb/ft^2

d. Thermal Performance: The Q of this system is 80 $Btu/hr/ft^2$. The ρK of this system is 0.068 $Btu/lb/hr-{}^oF-ft^4$.

6.1.7 Pour Foam Blocks Plus Foam Blankets

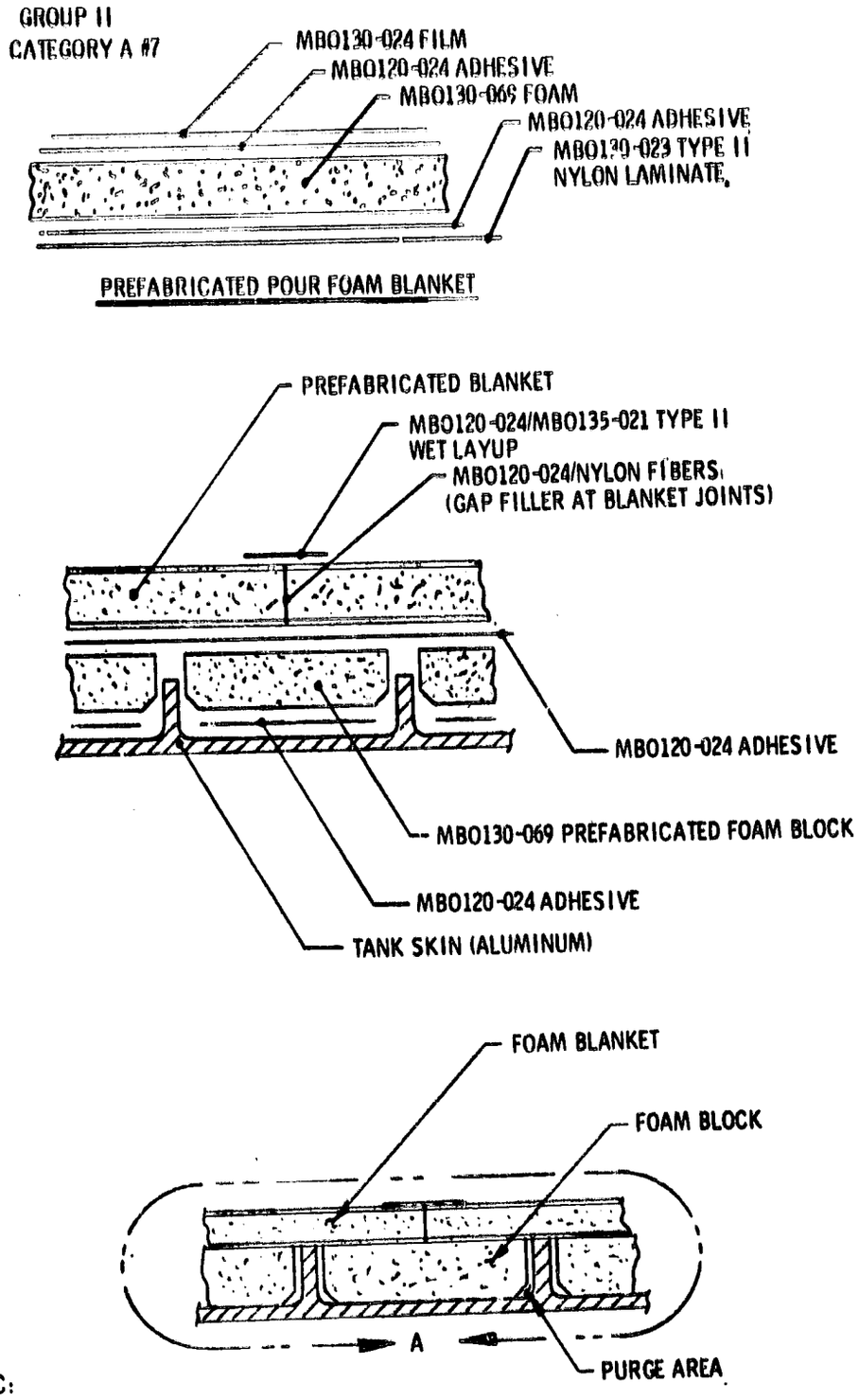
6.1.7.1 Description

This insulation system was used on S-II-1 through S-II-5 in the area of Cylinder 1-bolting ring (V7-532400 and V7-531001). The foam blocks and blankets are purged with helium gas. The thermal characteristics are similar to the helium purged system described in Paragraph 6.1.1.1.

The pour foam blocks plus blankets concept is shown in Figure 6.1.7.1-1. The foam blocks are prefabricated to required configuration and then bonded to the tank structure. The foam blankets are a bonded composite consisting of a prefabricated pour foam panel sandwiched between a plastic gas barrier film and a nylon fabric laminate. The composite is then bonded to the foam blocks previously bonded to the tank structure. The butt joints of the blankets are then sealed with a filler and wet layup.

6.1.7.2 Application

a. Utilization: This system can be utilized in applications involving complex geometry. It is particularly applicable where environmental or fabrication conditions are not amenable to spray operations.



PROCESS SPEC:
MA0606-033

Figure 6.1.7.1-1. Pour-Foam Blocks Plus Blankets

b. Performance: This system was used on five flight vehicles, all of which were flown successfully. In combination with the other insulation system on the stage, it has provided the required degree of thermal protection.

c. System Limitations: Limitations are the same as those described in Paragraph 6.1.5.2.

d. Design Problems: Design problems associated with the system were principally debonds of the foam blocks to tank skin and debonds between the foam blocks and outer blanket. Solution to the problems was to control the thickness of the primer system and the adhesive bond line.

e. Verification: Tests were conducted to verify the adequacy of the design of this system as used on the first five flight vehicles. These tests were conducted on 30-inch by 30-inch test tanks with the foam system subjected to cryogenic cycling simultaneously with aeroheating and vibration simulation (SID 63-600-8).

6.1.7.3 Thermal Performance

Thermal performance characteristics are the same for both spray foam and pour foam blocks and blankets (see Paragraph 6.1.4.3).

6.1.7.4 Structural Performance

The structural performance characteristics of the pour foam block plus pour foam blanket insulation system are identical to those described for the spray foam systems in Paragraphs 6.1.4.4 and 6.1.5.4. In addition, the design of the pour foam block system as used on the Saturn S-II results in gaps between the foam block and tank stringers as shown in Figure 6.1.7.1-1. Hence, during ranking and testing operations, and during launch ascent, differential burst pressure is exerted across the outer foam composite layer resulting in bending and shear stresses in the foam in addition to the thermal stresses previously mentioned in Paragraph 6.1.4.4.

6.1.7.5 Materials and Processes:

a. Materials:

1. Foam: Polyurethane, two-component, three-pound density, foam-in-place material (MB0130-069).

2. Adhesive Resin: Polyurethane, two-component, low-temperature curing (MB0120-024).

3. Nylon Fabric: Phenolic resin pre-impregnated nylon fabric for laminate fabrication (MB0130-023 Type II).

4. Woven Nylon Fabric: Nominal 0.005-inch-thick fabric (MB0135-021 Type II).

5. Plastic Film: Polyvinyl fluoride gas permeability barrier (MB0130-024).

b. Processes: Fabrication and installation of the prefabricated pour foam blanket insulated system is specified in MA0606-033.

1. Material Storage and Handling: All materials are stored and handled in accordance with the requirements of their material specifications.

2. Environmental Control: Temperatures between 65 and 90 F and a maximum relative humidity of 70 percent are required in the immediate working area during foaming and bonding operations.

3. Foam Block Fabrication: Blocks of foam insulation (MB0130-069) are fabricated for bonding into irregular surfaces and fabrication of the composite overlay sheet.

(a) Molds: To provide containment for rising pour foam, open or closed molds are assembled to produce foamed blocks conforming to the engineering drawing or capable of being shaped, by sanding or cutting methods, so as to conform to the engineering drawing. The molds are preheated to 110 ± 10 F and the direction of rise is perpendicular to the primary bonding interface.

(b) Material Calculations: For each cubic inch of detail block volume in closed molds, 0.80 ± 0.04 gram of mixed MB0130-069 components are used. For open molds, this amount is increased as necessary to fill the mold completely.

(c) Mixing and Delivery:

(1) Component materials, proportioned in the ratio specified by the manufacturer, are mixed for 23 ± 2 seconds using a propeller-type mixer operating at 1720 ± 250 rpm to produce a mix of uniform color and of minimal air inclusion.

(2) The mixed components are then poured rapidly into the pre-heated molds in a manner that will prevent voids due to air inclusions in the mold.

(d) Cure: The foam block is cured at 110 ± 10 F for five minutes and allowed to remain in the mold for a total of 30 minutes. Machining to final dimensions is allowed two hours after the initiation of pouring.

4. Foam Block Bonding:

(a) Surface Preparation: Tank wall faying surfaces must be wiped with MEK. Foam blocks are lightly sanded and vacuumed to remove foam dust. All faying surfaces, including foam surfaces, are then brush-coated with polyurethane resin (MB0120-024), mixed 50 percent by volume with MEK and allowed to air-dry a minimum of 15 minutes.

(b) Adhesive Application: Polyurethane adhesive resin (MB0120-024) is applied to the underside of the foam block in a smoothly crowned layer using 0.45 ± 0.05 gram of resin per square inch of faying surface. The resin layer extends to within 1/4 inch of each of the short edges of the block surface.

(c) Assembly and Cure: The foam block, having applied adhesive resin, is placed in position within 10 minutes of adhesive application under a uniform bonding pressure of 1 to 3 psi. The assembled configuration is allowed to cure 16 to 24 hours, depending on the ambient temperature before further bonding operations.

5. Composite Overlay Sheet Fabrication: As detailed in Figure 6.1.7.1-1, the composite blanket is constructed by bonding different facing sheet materials to either side of a foam block which is fabricated as described previously.

(a) Facing Sheets: The outboard facing sheet consists of a gas-barrier film (MB0130-024). The inboard facing sheet is fabricated from two plies of pre-impregnated nylon fabric (MB0130-023) processed in accordance with the requirements of MA0605-003.

(b) Bonding: A double box coat of MEK-thinned polyurethane resin (MB0120-024) is applied to all faying surfaces and air-dried a minimum of 15 minutes. The composite is assembled and cured under vacuum of 28 ± 2 inches of mercury for 16 to 24 hours, depending on the ambient temperature, before further bonding operations.

6. Bonding of Composite: The inboard surface of the composite overlay sheet and the outer foam surface in the corresponding bolt ring cavities are brush-coated with one coat of MEK-thinned polyurethane resin (MB0120-024) and air-dried for 15 minutes minimum. One coat of unthinned polyurethane resin, 0.008 ± 0.004 inch thick, is then applied to the foam block surfaces in the bolting ring cavities. The composite overlay sheet is assembled onto the corresponding bolting ring cavity, avoiding all air entrapments or contamination of metal stringers with adhesive. Bonding pressure is applied and the detail cured 16 to 24 hours. Two coats of unthinned resin are applied to all exposed foam edges of the composite facing sheet, allowing 12 hours between coats.

7. Joint Overlays: Cut strips of nylon fabric (MB0135-021 Type II) overlapping composite joints by 3/8 inch, are applied with 0.008-inch-thick polyurethane resin and allowed to cure 16 to 24 hours at ambient pressure and temperatures.

6.1.7.6 Manufacturing

a. Description: Four foam blocks plus foam blankets were fabricated in a manner similar to that described in Paragraphs 6.1.5.6 and 6.1.6.6.

Pour foam blocks were manufactured by pouring a foam mixture into a tool mold of the approximate size needed. The tool mold was made of rubber-like material for ease of removing the foam blocks.

Foam blocks were then fitted to the spacecraft, trimmed, sanded to size, and bonded to the substrate surface.

Foam blankets were manufactured by machine-mixing the pour foam ingredients and pouring into a large mold (approximately 4 feet by 8 feet). The foam was allowed to expand to a height of approximately 3 inches. The foam bun was removed from the mold after partial cure, and allowed to cure. After cure the bun was mounted on a special bandsaw table where sheets of foam were sawed, then squared at edges to blanket size.

A thin plastic laminate was fabricated from nylon and resin. The plastic laminate and the foam panel were bonded together to form a blanket. A Tedlar film was bonded on the opposite side to form a gas barrier.

Foam blanket assembly was then located and fit to the Cylinder 1-bolting ring area. After fit-check the bond surfaces of the blanket and foam blocks were covered with adhesive, the panels located, vacuum bagged, then cured. The vacuum bags were removed and gaps between the blankets were filled with nylon fibers and adhesive, then sealed with a wet layup tape and cured.

The fabrication and installation sequence for pour foam plus foam blankets is shown in Figure 6.1.7.6-1.

b. Tooling and Equipment: Tooling consisted of a pour foam tool for blocks, a large mold for the blankets, and a platen for making the plastic laminate sheet and bonding the blanket assembly.

Equipment consisted of foam mixing chamber, roller tables, special bandsaws, vacuum pumps and accessories, and miscellaneous spatulas, sandpaper, and mixing containers.

6.1.7.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0606-033).

1. Application of Primer (MB0120-032) per MA0106-045: The bolting ring and Cylinder No. 1 subassemblies were primed with MB0120-032 and heat-cured in the detail prior to assembly in the vehicle stack. The primer system was identical to that employed in the basic inuslation design. Quality control measures are established in Paragraph 6.1.1.7-b-1.

2. Foam Block Fabrication: The quality control provisions were as noted in Paragraphs 6.1.6.7-b and 6.1.6.7-c-1.

3. Foam Blanket Detail Fabrication:

(a) Foam: Same as in Paragraph 2 above.

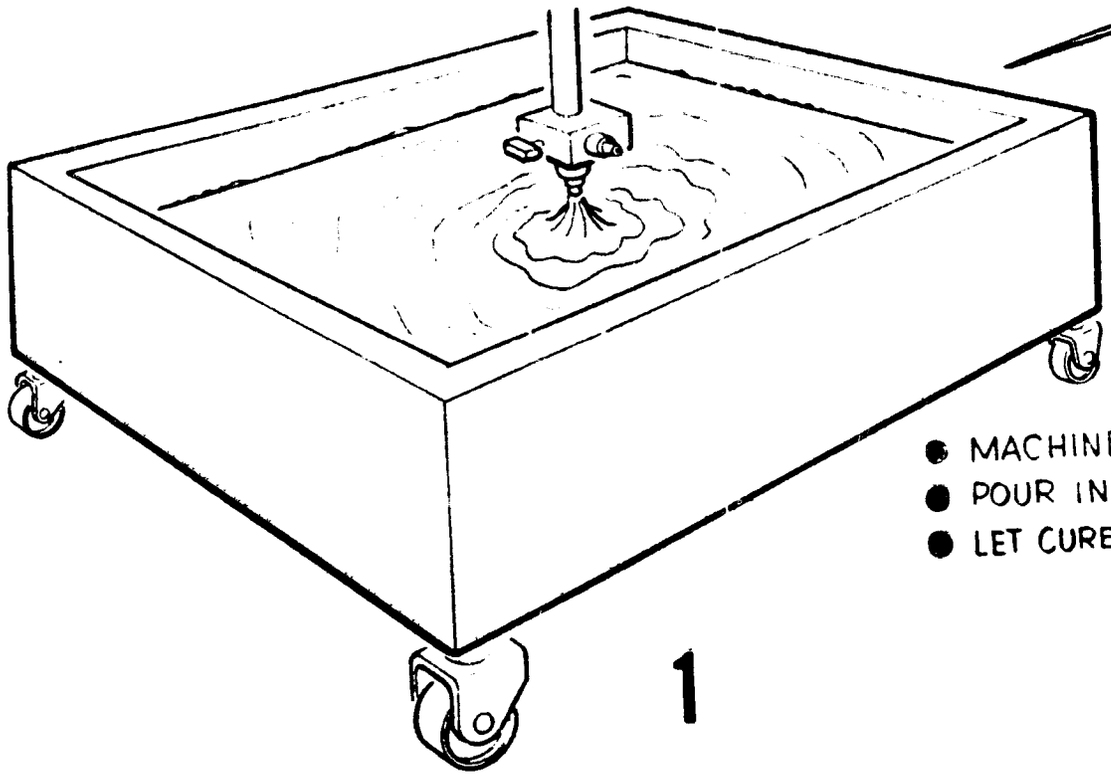
(b) Nylon Laminate: The laminate was fabricated in accordance with MA0605-003. Quality control provisions are noted in Paragraph 6.1.5.7-a.

(c) External Gas Barrier Film: The external film material was Tedlar, procured to the requirements of MB0130-024.

4. Foam Blanket Detail Bonding: Flatwise tensile strength test coupons were fabricated and cured simultaneously with the bonding of the foam blanket details into the final insulation composite. The test coupons contained an identical buildup of materials as contained in the blanket composite: Tedlar film, foam, and nylon laminate. Testing was conducted per ASTM D-1623, Method B.

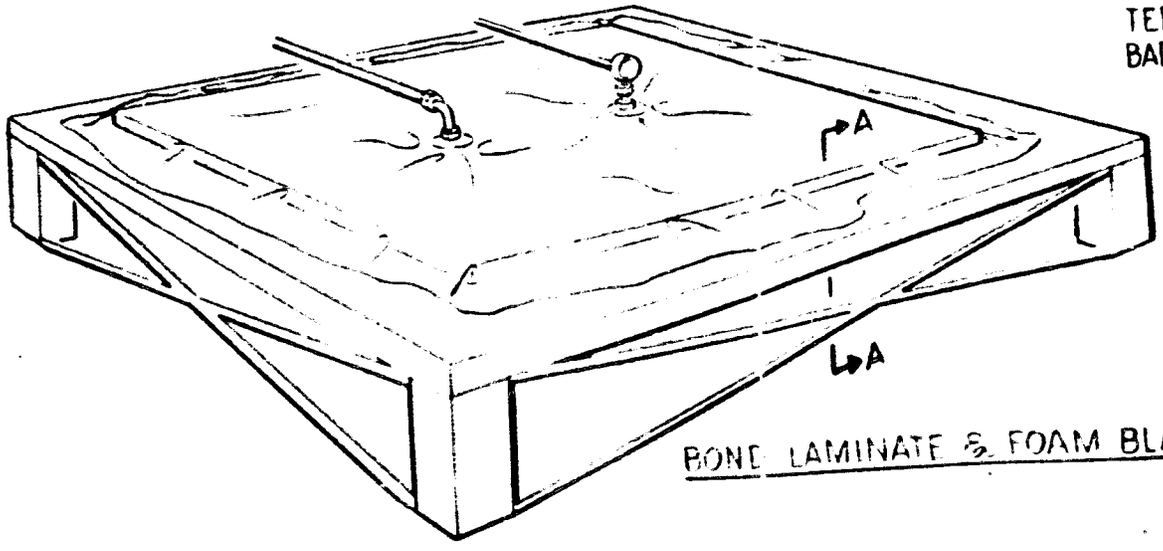
5. Foam Block and Blanket Installation: The foam blocks were bonded to the bolting ring structure using polyurethane adhesive (MB0120-024) and mechanical bonding pressure of 1-3 psi. After a minimum 24-hour cure, the insulation blankets were bonded to the blocks with MB0120-024 adhesive. In each bonding operation, flatwise tensile test coupons were fabricated simultaneously with the production bonding operation. Testing was conducted per ASTM D-1623, Method B.

c. System Checkout (MA0201-4266): Following completion of all subassembly installations, the entire insulation system encompassing the Cylinder No. 1 - bolting ring area was subjected to a final functional checkout.



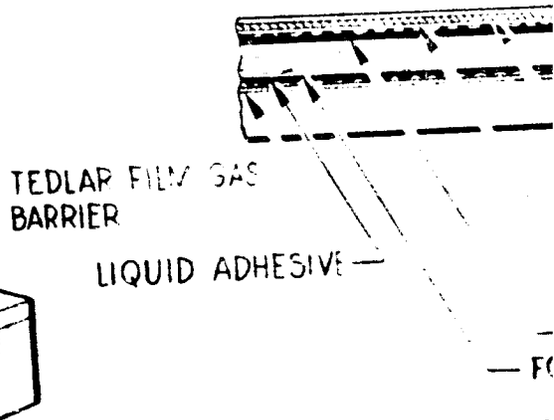
- MACHINE MIX POUR FOAM
- POUR IN LARGE MOLD
- LET CURE

1



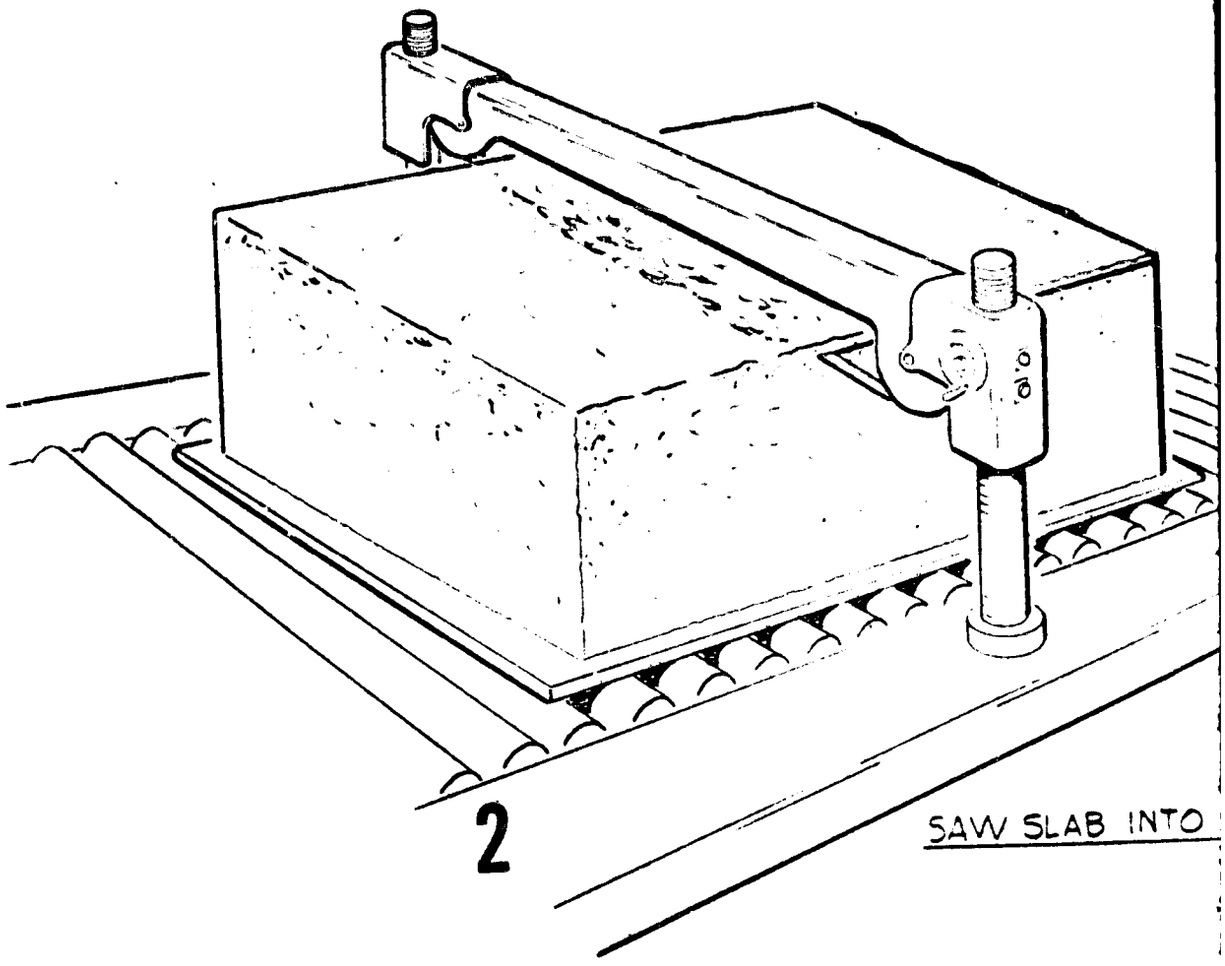
BOND LAMINATE & FOAM BLANKET

4



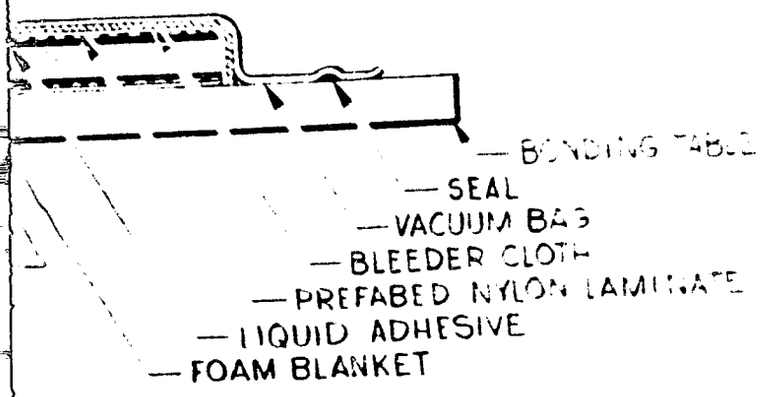
SECTION A

FOLDOUT FRAME

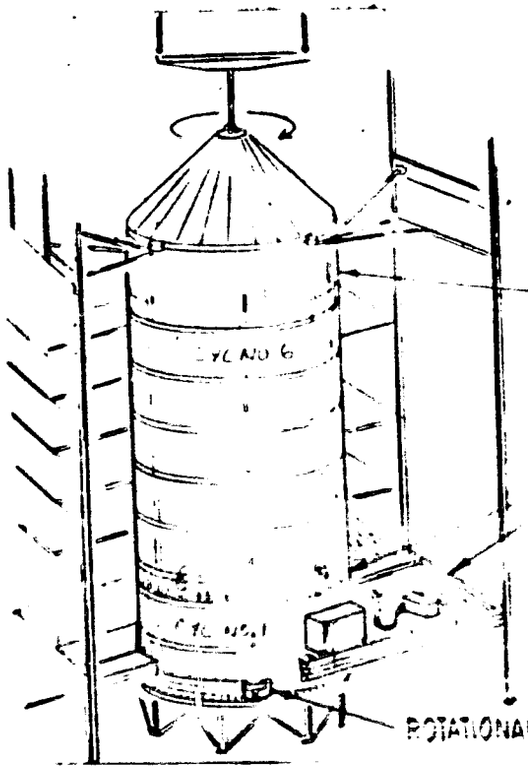


2

SAW SLAB INTO

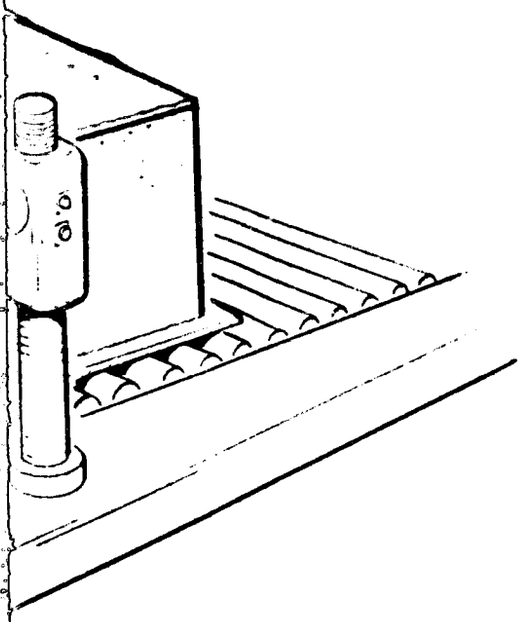


SECTION A-A

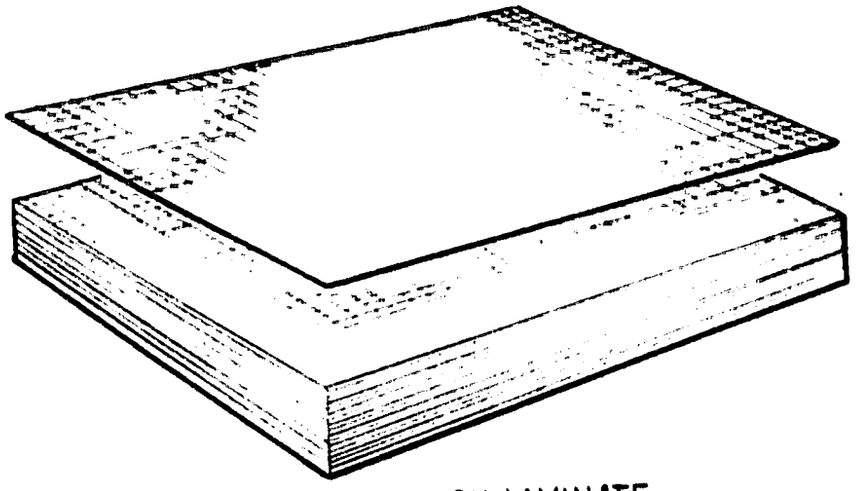


5

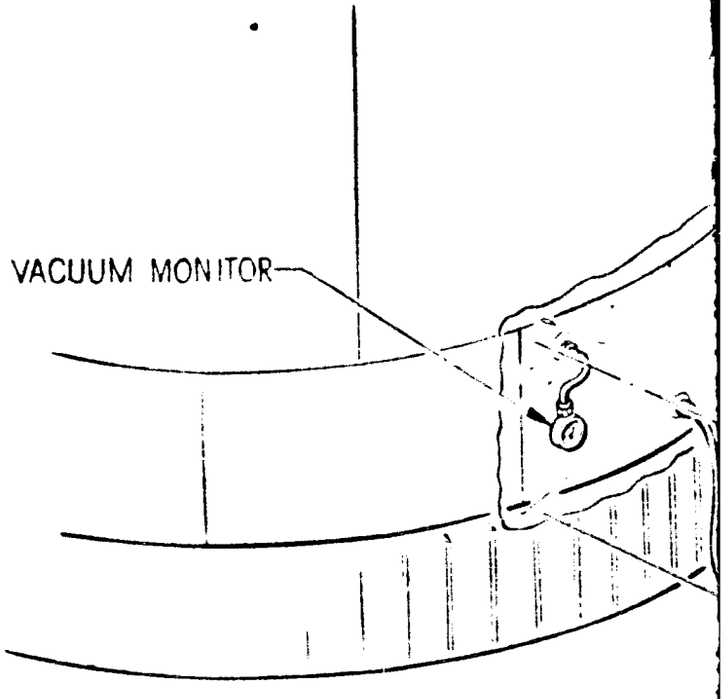
FOLDOUT FRAME 2



N SLAB INTO SHEETS



PREFAB NYLON LAMINATE



NWARD SKIRT INSULATION

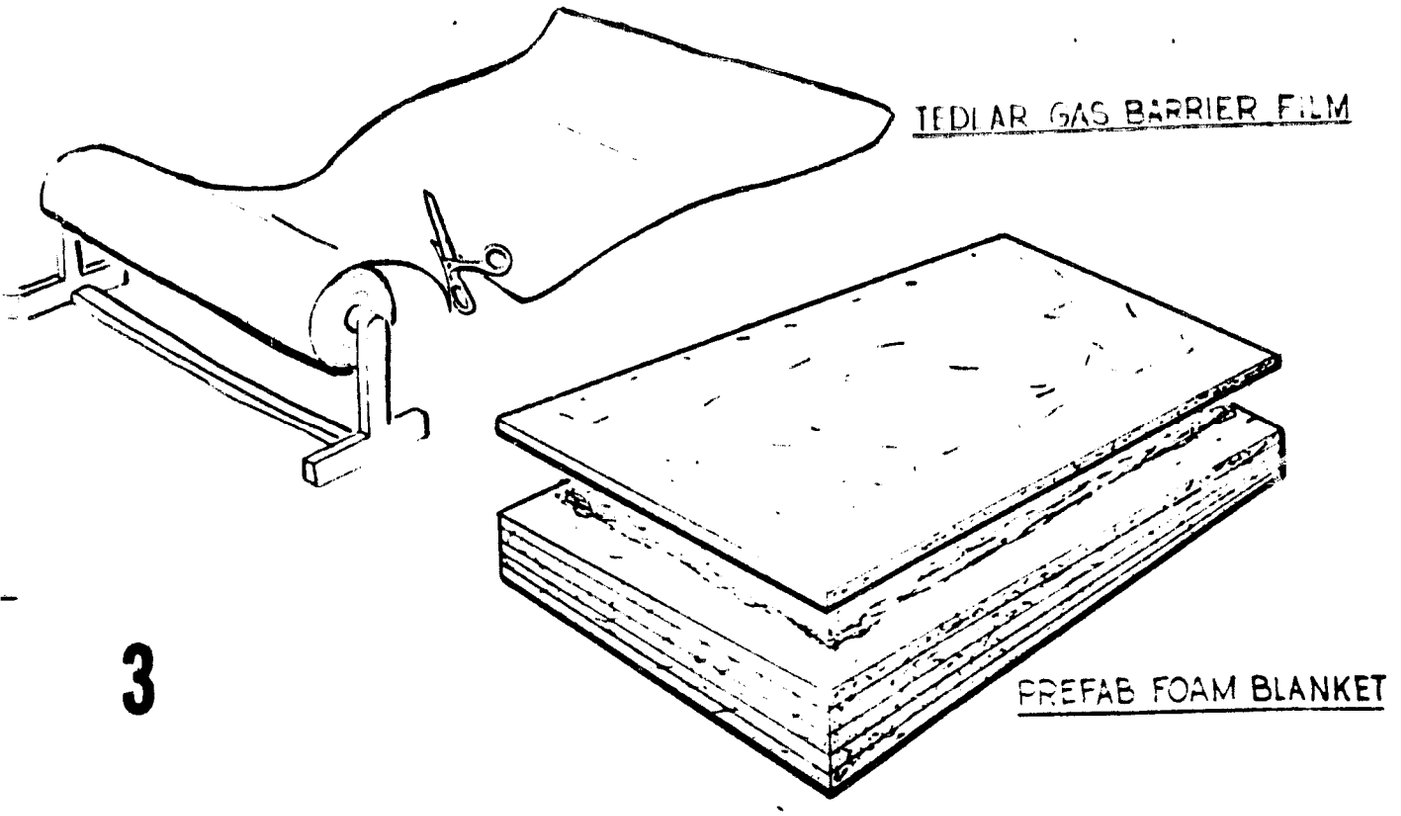
CYLINDER NO. 1 & BOLTING RING INSULATION

VATING PLATFORM

VACUUM BOND PANELS TO STA

5

FOLDOUT FRAME 3



3

TYPICAL OPERATIONS

- APPLY ADHESIVES
- INSTALL BLANKET
- VACUUM BAG & CURE
- FILL JOINTS(ADHESIVE & [illegible]N FIBERS)
- APPLY WET LAYUP OVER JOINTS

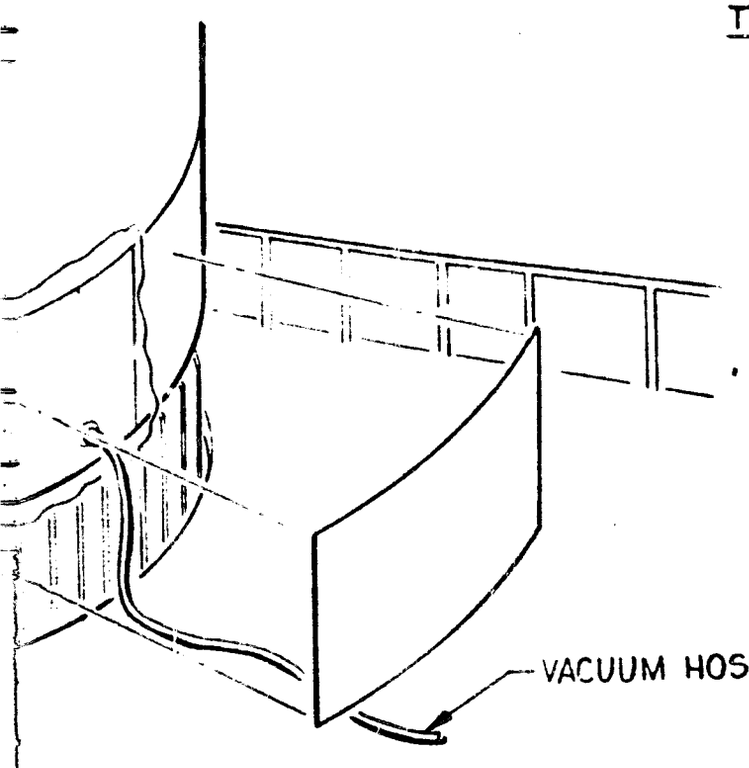


Figure 6.1.7.6-1. Pour Foam Plus Foam Blanket

O STAGE

6

FOLDOUT FRAME 4

The inspection sequences consisted of a comprehensive visual, leak check, proof pressure, and final verification of leakage and ultimate flow rate.

1. Leak Check: The insulation system was slowly pressurized to two psig with gaseous nitrogen and leak-checked per the bubble fluid technique described in MA0615-003.

2. Proof Pressure Test: Using gaseous nitrogen, the system was pressurized to 0.5 psig in approximately five minutes and held for ten minutes. The time, temperature, flow rate, and pressure was recorded at two-minute intervals. Using the same procedure, the system was ultimately pressurized to 2.6 to 3.0 psig. Maximum allowable leakage at this pressure was 150 scc/sec (0.32 scfm).

6.1.7.8 Repair and Maintenance

a. Repair: No structural repair procedures were developed. The insulation system exhibits a high adhesion mortality rate following cryogenic exposure. Successful repair of foam block debonds was accomplished by rebonding to a bare aluminum tank wall with glass fabric-reinforced epoxy adhesive (MB0120-023).

b. Maintenance: No special maintenance procedures are required.

6.1.7.9 Reliability

The only identified failure mode is tearing away. Results are presented in Table 6.1.7.9-1.

Table 6.1.7.9-1. FMEA - Pour Foam Blocks Plus Blankets

Subsystem or Component	Failure Mode	Mission Effects Remarks
Cylinder No. 1 and Bolting Ring Foam Blocks, Bonded	Tears Away From Structure	Possible mission scrub. Increased boiloff, heat transfer rate increased.

6.1.7.10 Safety

This insulation system uses pour foam in two different applications. Safety requirements for pour foam are described in Paragraph 6.1.6.10.

6.1.7.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The

following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 39 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are not available.

c. Weight: The total as-installed weight is 0.813 lb/ft^2 broken down as follows:

1. Film (MB0130-024) - 0.0172 lb/ft^2
2. Adhesive (MB0120-024) - 0.0600 lb/ft^2
3. Foam, 3 lb/ft^3, 0.50-inch thick (MB0130-069) - 0.1253 lb/ft^2
4. Adhesive (MB0120-024) - 0.0600 lb/ft^2
5. Type II Nylon (MB0130-023) - 0.0546 lb/ft^2
6. Adhesive (MB0120-024) - 0.0600 lb/ft^2
7. Foam, 1.50-inch thick (MB0130-069) - 0.3758 lb/ft^2
8. Adhesive (MB0120-024) - 0.0600 lb/ft^2

d. Thermal Performance: The Q of this system is 140 btu/hr/ft^2. The ρK of this system is 0.084 btu-lb/hr-°F-ft^4.

6.1.8 Cork - Bonded Over Foam

6.1.8.1 Description

The cork-bonded over foam system was developed for use on the S-II stage in conjunction with the spray foam insulation (V7-531247). Aerodynamic heating and aeroshear cause excessive erosion of unprotected spray foam in protuberance-influenced regions. This system is designed to provide erosion protection for spray foam insulation in these areas.

The configuration shown in Figure 6.1.8.1-1 is a typical protuberance-influenced region with the protective system installed.

The bonded-in-place design is shown in Figure 6.1.8.1-2. A rail assembly consisting of foam-filled honeycomb core and bonded cork is prefabricated for use in ramp areas and is shown in Figure 6.1.8.1-3. The rail assembly is bonded to the tank skin, foam is sprayed in place on either side of rail, and then cork sheet is bonded over the foam surface. This configuration, along with the outer coating, is shown in Figure 6.1.8.1-4.

A nylon wet layup is installed in the area of the aerodynamic fairings to satisfy structural requirements. The configuration is shown in Figure 6.1.8.1-5.

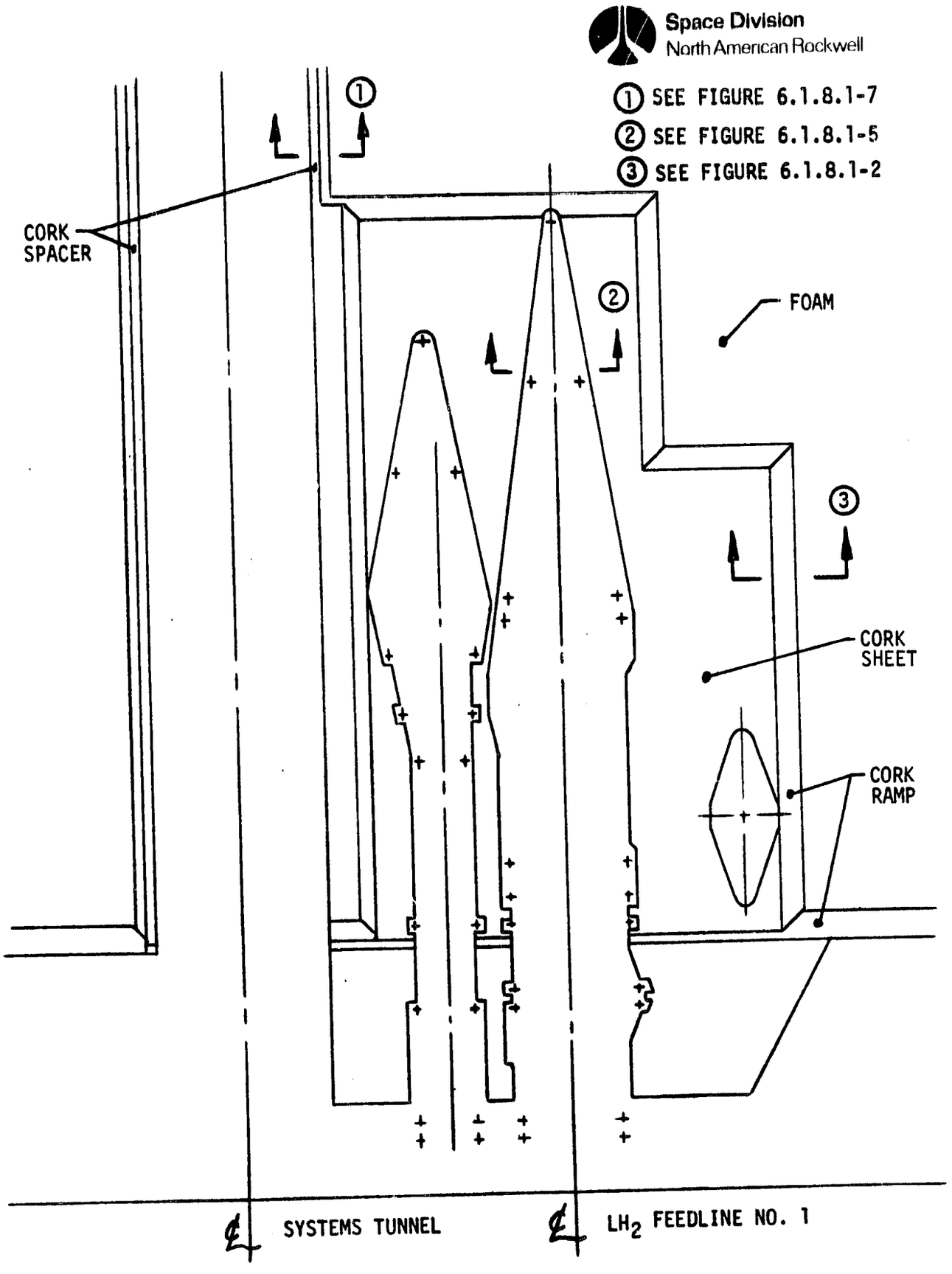


Figure 6.1.8.1-1 Orientation View Looking Inboard at S-II LH_2 Tank Sidewall

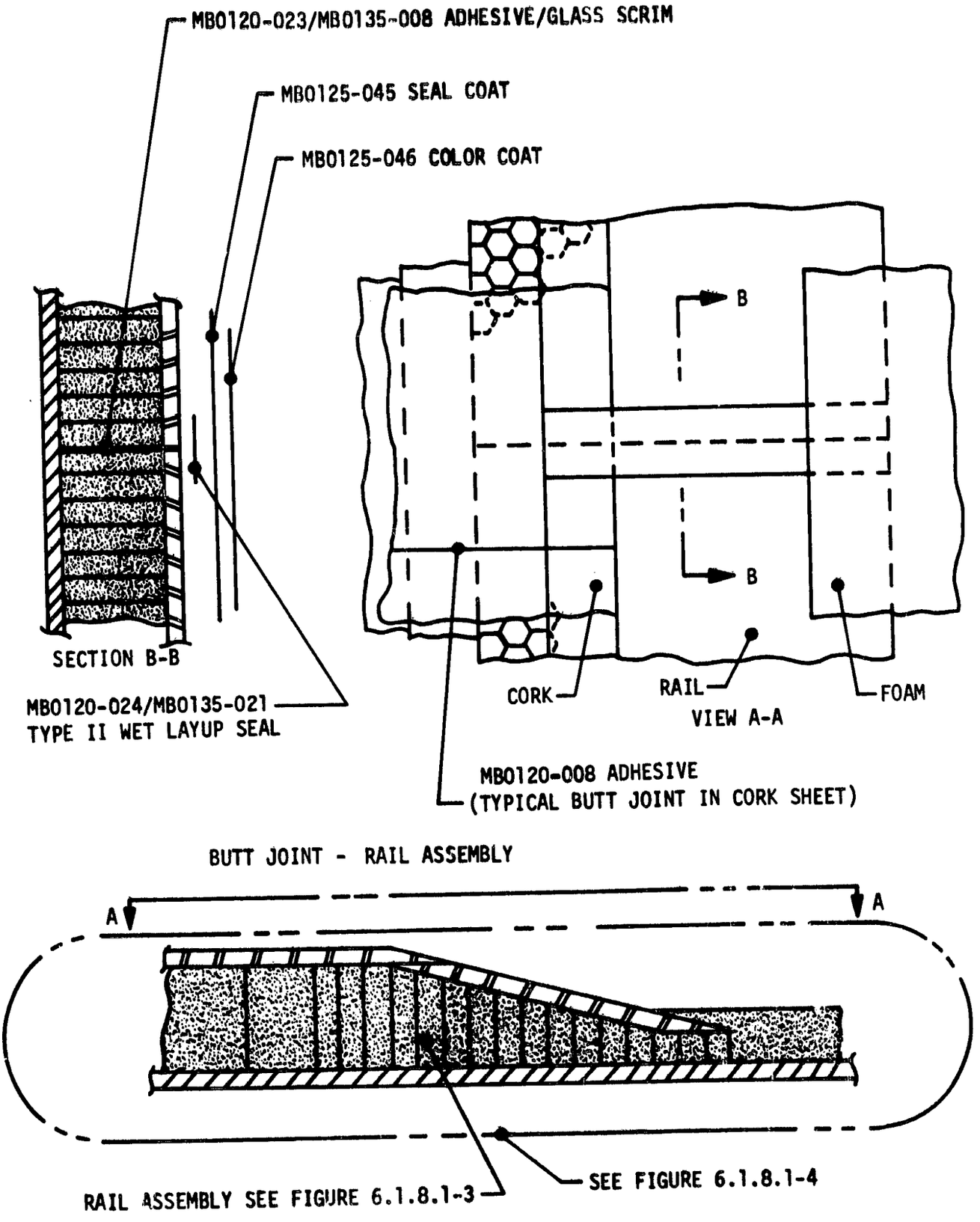


Figure 6.1.8.1-2 Bonded Cork Concept

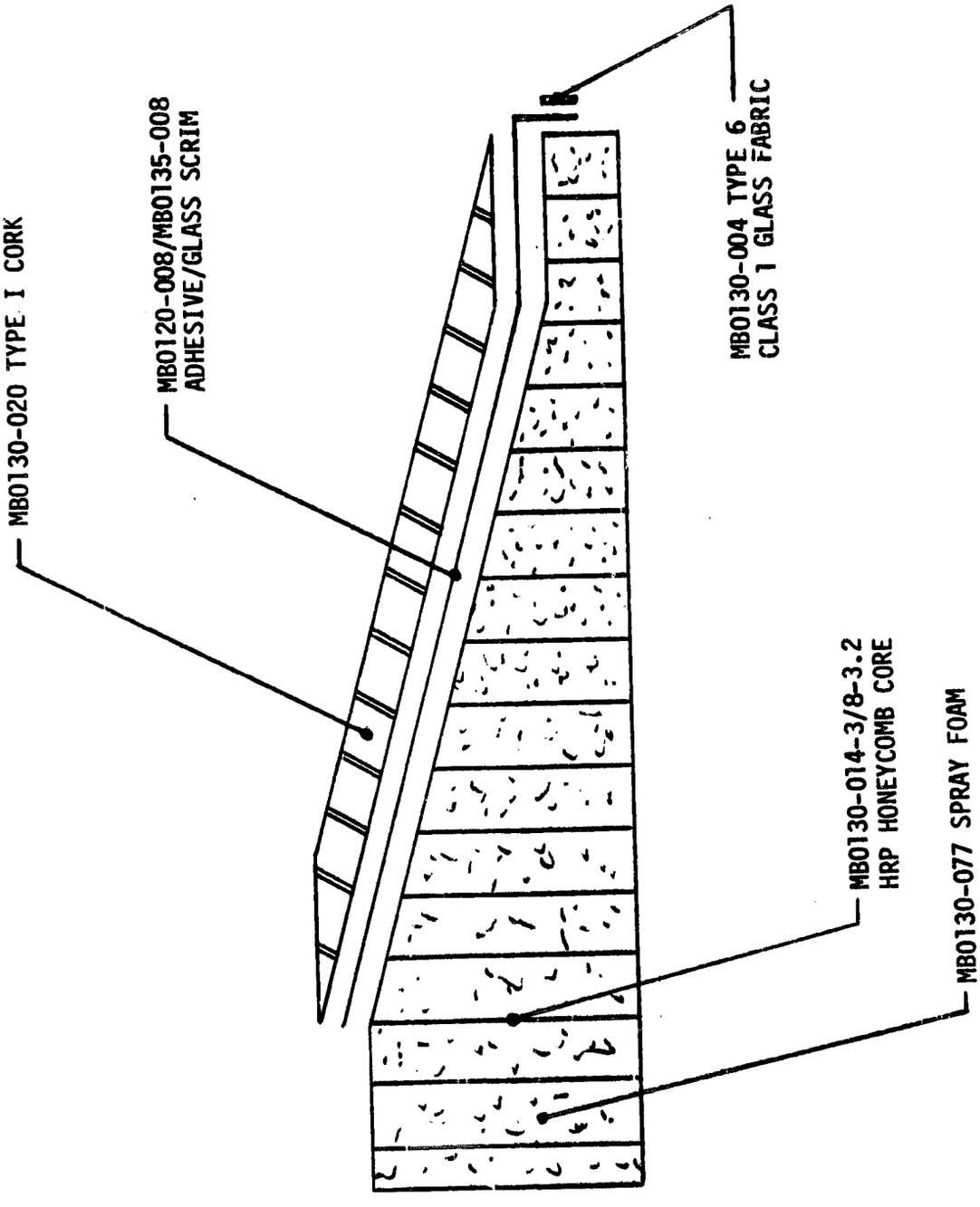


Figure 6.1.8.1-3 Rail Assembly

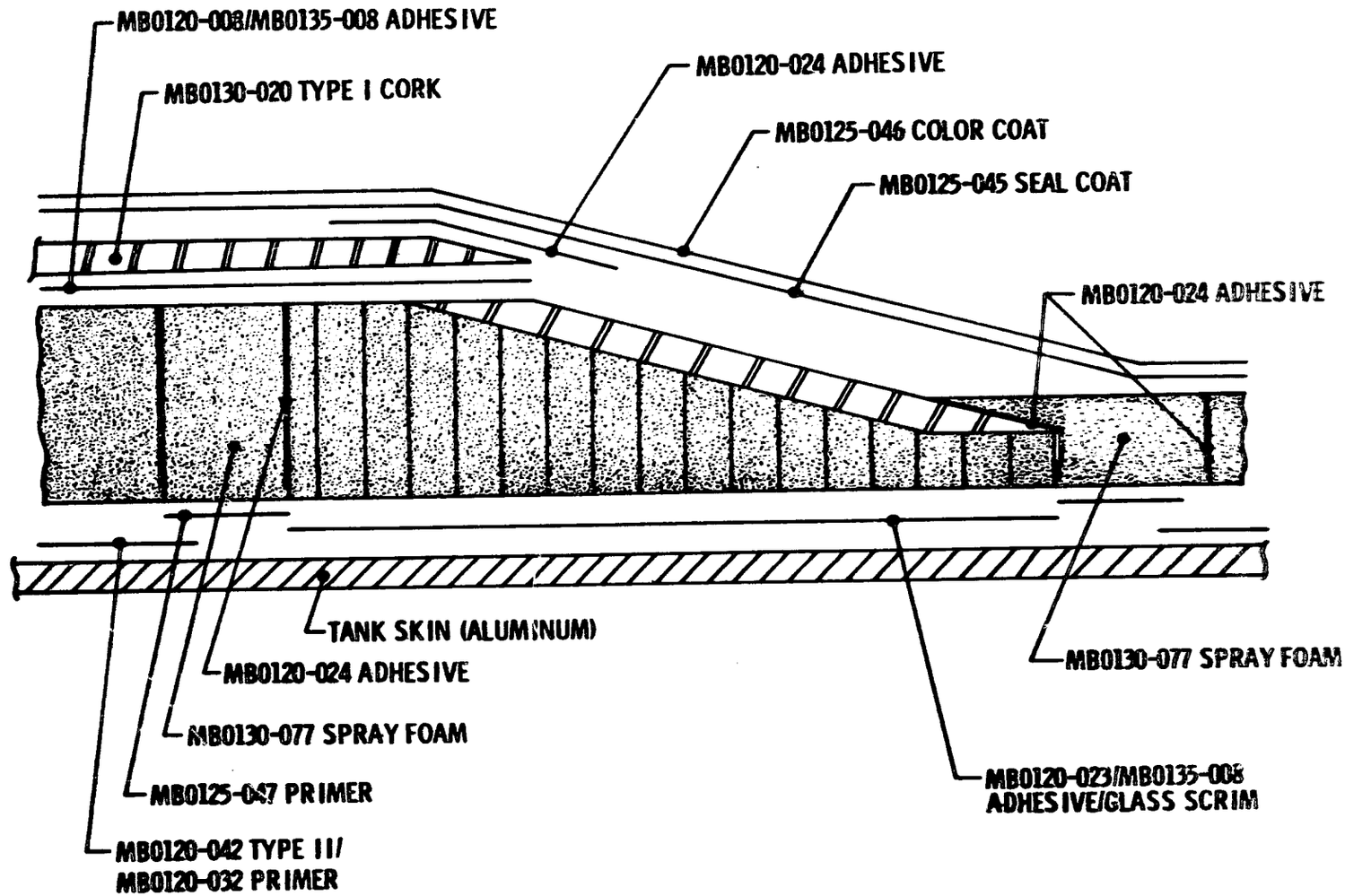


Figure 6.1.8.1-4. Cork and Rail Installation

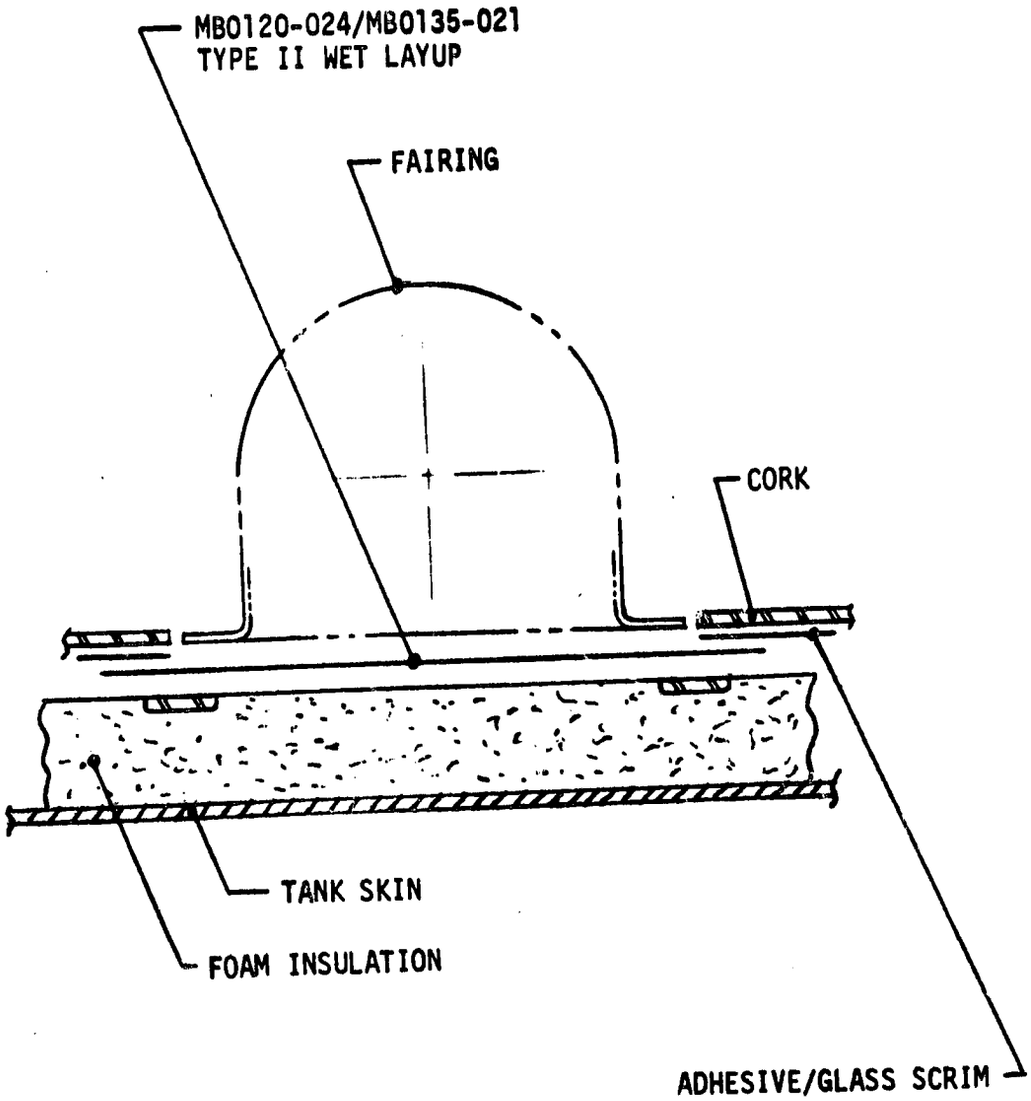


Figure 6.1.8.1-5. Wet Layup Under Fairing

A standoff configuration used at aerodynamic fairing attach points is shown in Figure 6.1.8.1-6. This design isolates any cryopumped air and revaporization associated with leakage around the standoff spacers.

The mechanically attached design is shown in Figure 6.1.8.1-7. A cork sheet spacer is installed in a recess in the spray foam insulation and is retained by the systems tunnel structure.

6.1.8.2 Application

a. Utilization: The cork/foam system is unique to the S-II stage where a combined low thermal conductivity and high-temperature protection system is required. This system has utility such as on the nose cone or leading edges of space vehicles where similar performance requirements must be met.

b. Performance Characteristics: This insulation system has been installed on nine S-II vehicles, six of which have been flown. Data from the flight have indicated no structural failures or resulting thermal degradation of the insulation system.

c. System Limitations: This system was developed to meet the requirements of the S-II program as discussed in Section 5.0. The materials and configurations are limited to the constraints of that program. Limitations are based on prelaunch and flight temperatures and tank strain conditions that prevailed in the selections of materials and processing variables.

   The system is limited to the prelaunch temperatures shown in Figure 6.1.8.2-1. During boost the maximum cork-to-foam bondline interface is limited to 200 F. Limiting tank strains are shown in Figure 6.1.8.2-2.

d. Design Problems: Principal design problems experienced during development of the cork/foam insulation system are summarized in Table 6.1.8.2-1.

Table 6.1.8.2-1. Cork Bonded to Foam - Problems and Solutions

Problems	Solution
Debond of rails from tank surface during stage cryogenic tests	Limit epoxy adhesive thickness to an equivalent 0.. to 0.3 gram/in.^{2} (0.023 in.) at contoured rail interface to tank surface mold line
Inadequate access to rails for bonding	Provide adequate access on all edges to allow access for installation and bonding

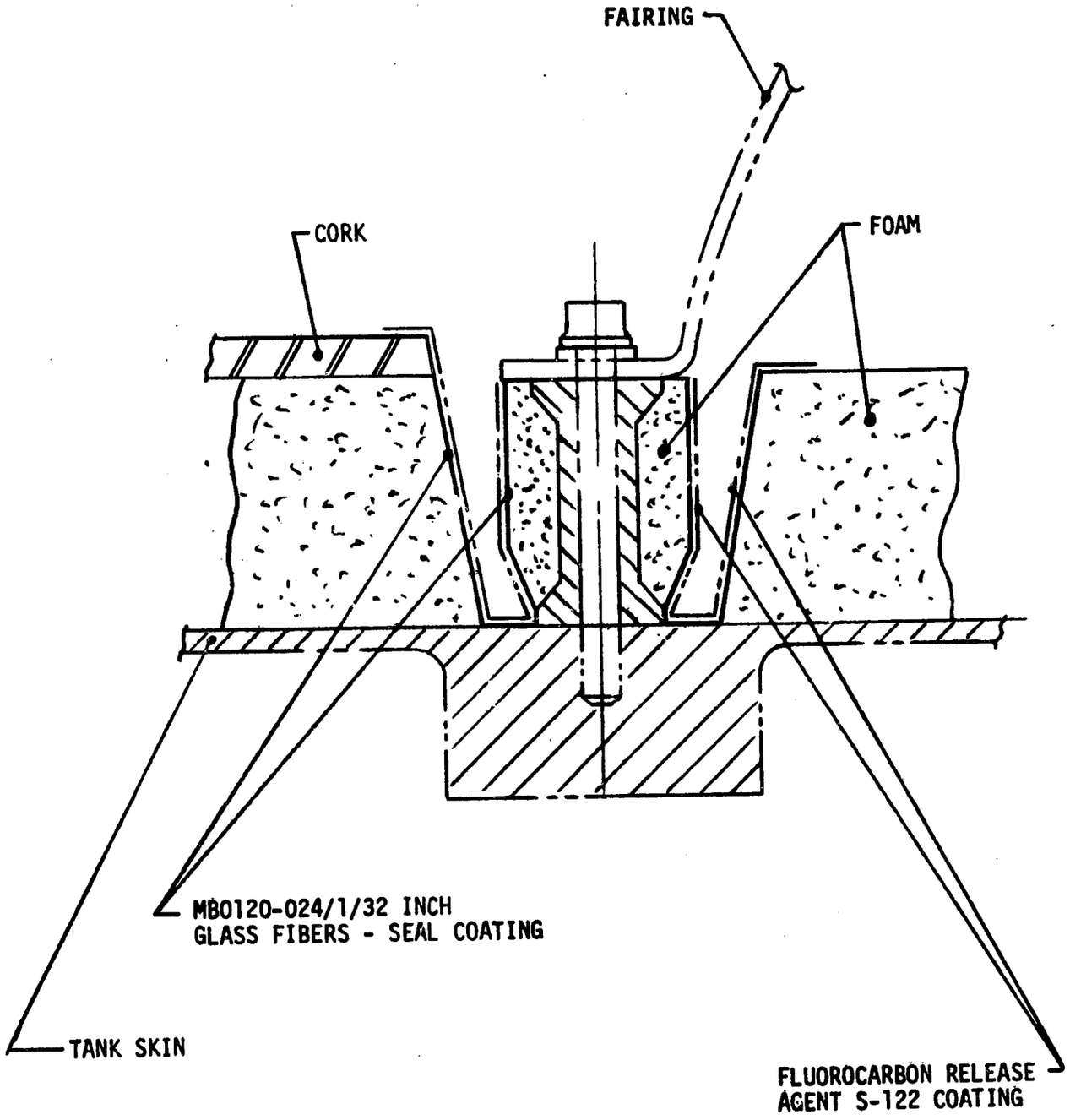


Figure 6.1.8.1-6. Standoff Installation

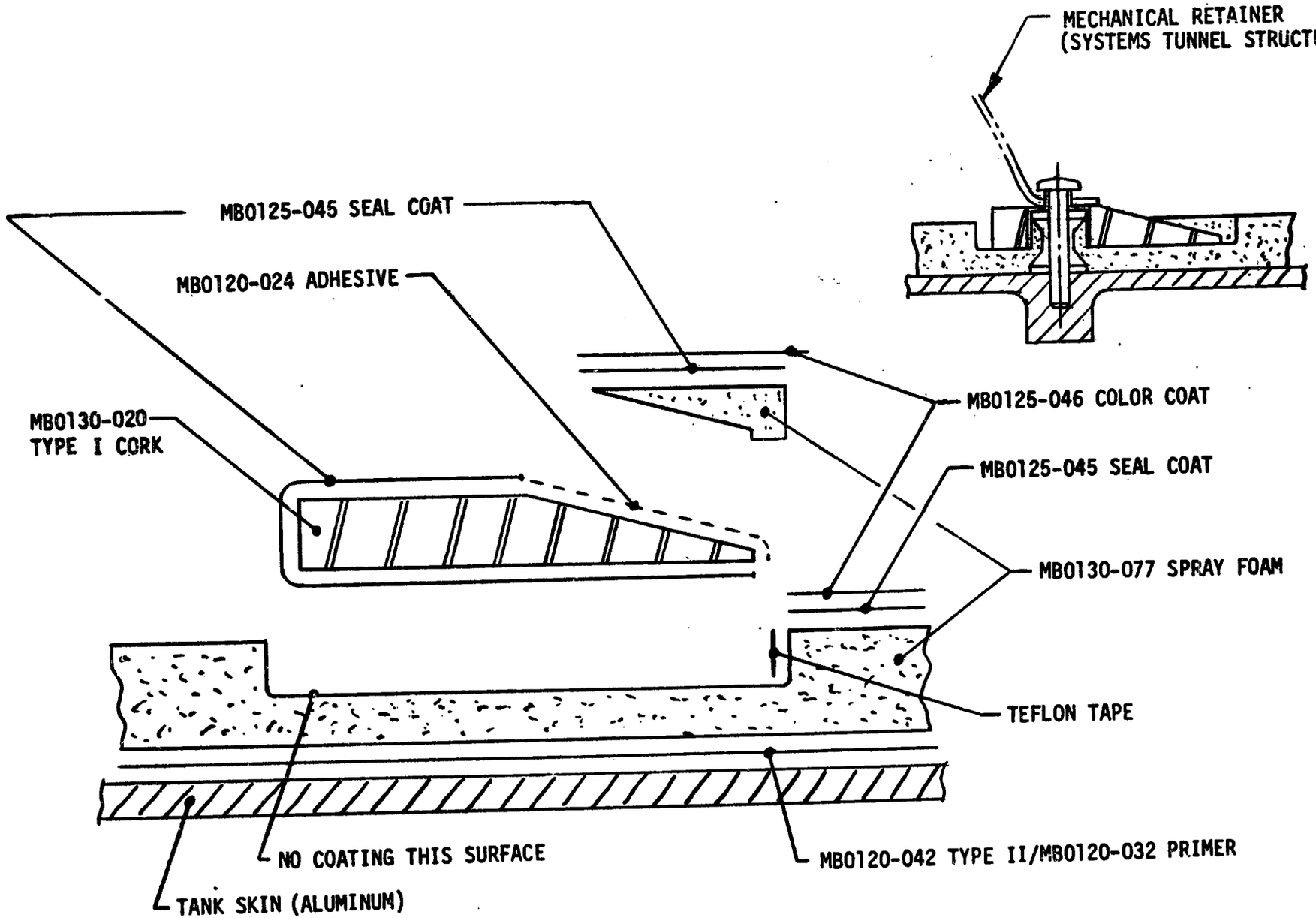


Figure 6.1.8.1-7. Mechanically Retained Cork Spacer

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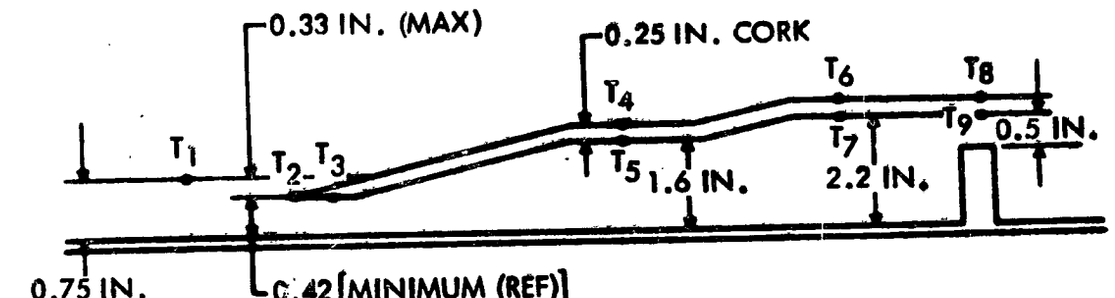


LOCATION	TEMPERATURE (F)
T_1	-105
T_2	-190
T_3	-170
T_4	-17
T_5	-27
T_6	-5
T_7	-13
T_8	-135
T_9	-160

Figure 6.1.8.2-1. Spray Foam Minimum Design Temperatures

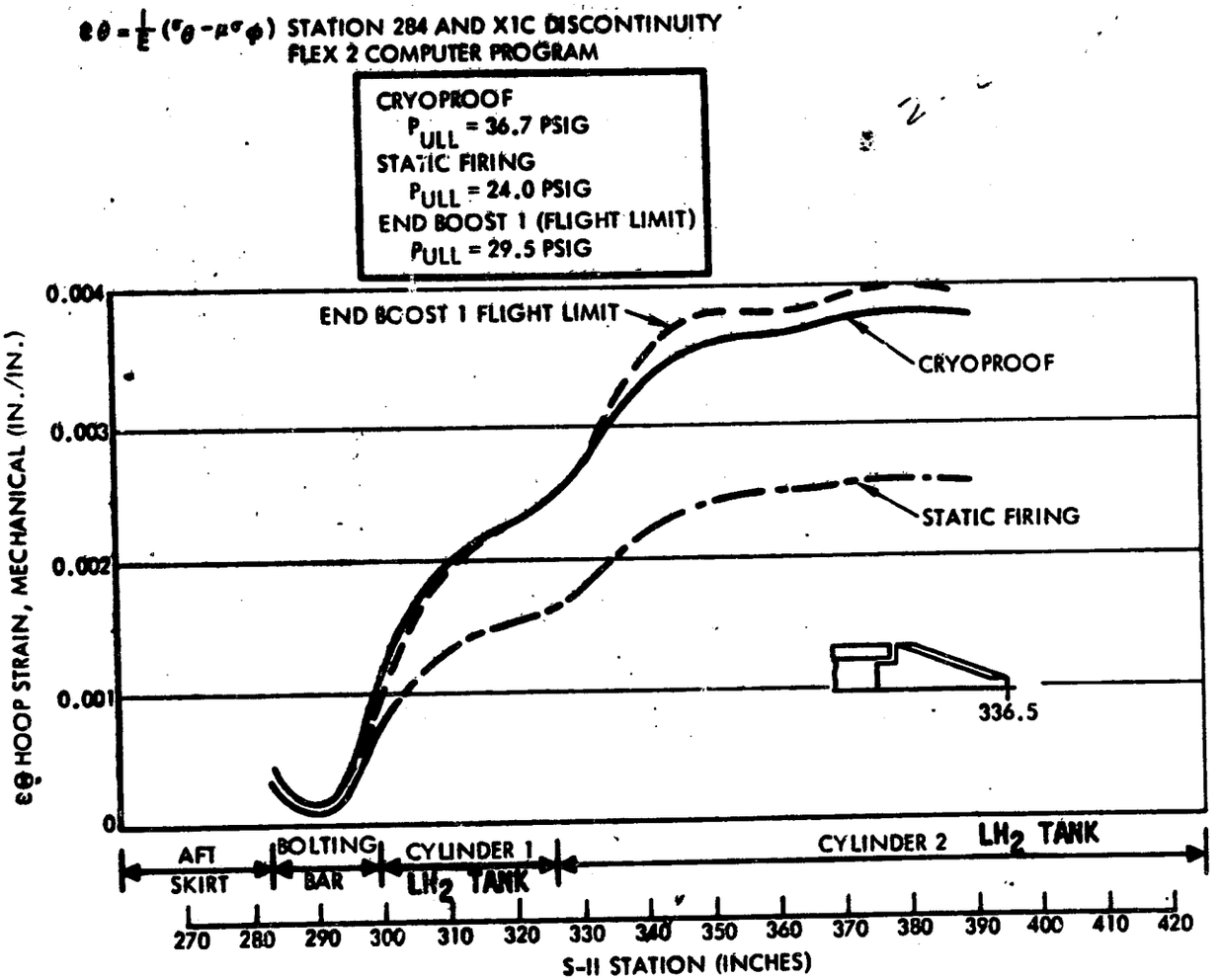


Figure 6.1.8.2-2. S-II-4 Hoop Strain Versus Distance Along Tank Wall

Table 6.1.8.2-1. (Cont)

Problems	Solution
Debonds of cork to foam associated with leakage around standoffs	Isolate standoffs from cork-foam interfaces.
Contamination of metal surface adjacent to rails	Provide masking and cleaning procedures that preclude residue from tape or chemicals in the bonding areas.
Corrosion at primer interfaces (MB0125-047/MB0120-032)	Allow a 1/4- to 1/2-inch overlap of primer MB0125-047 onto MB0120-032.

e. Design Verification Tests: A series of tensile (dogbone) tests and small panel tests were conducted to verify the cork bonded to foam design concept (SD 69-96). Figure 6.1.8.2-3 shows a typical dogbone tensile specimen. Small panel tests included the following:

1. A 30- by 30-inch test panel (Figure 6.1.8.2-4) with a ramp configuration that had inside and outside 90-degree corners. The panel was tested through five fill and drain cycles with aeroheating (peak of 445 F) and vibration imposed on the fifth cycle. The panel showed no signs of failure on post-test inspection.

2. A 30- by 30-inch test panel fabricated to the forward skirt configuration with the cork-foam ramps. The panel was cycled five times with LN_2 to simulate the temperature conditions on the forward skirt.

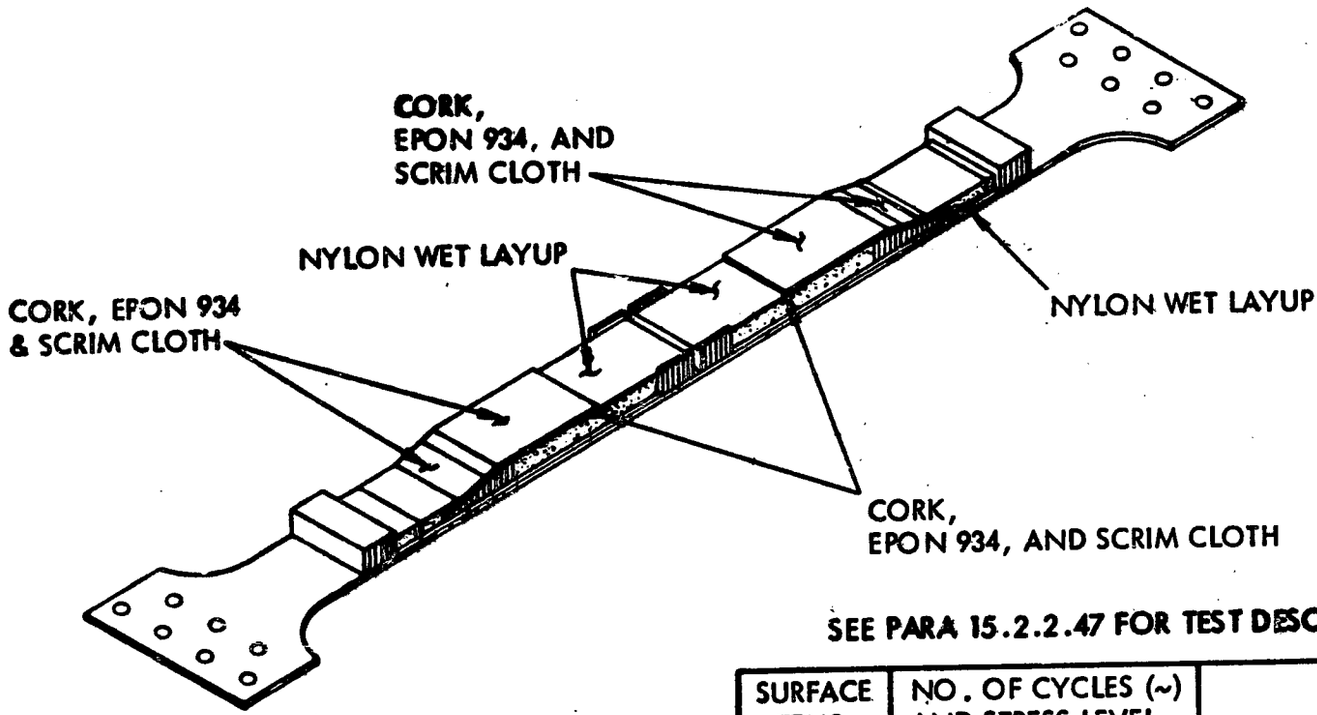
3. Aeroshear panels to verify the shear capability of the cork-foam adhesive system.

4. Cork debond panels to evaluate the limit size debond acceptable under pressure-cycling and static pressure conditions.

Design verification of mechanically attached cork was made through cryogenic tests conducted on the S-II stages. The system functioned as required with no problems experienced with the design.

6.1.8.3 Thermal Performance

An important thermal performance characteristic of cork is its use as an erosion-protection system to limit the surface erosion of the basic foam (spray-on or pour) due to aerodynamic heating and shear stress encountered during S-IC/S-II boost. The cork surface coating provides a heat sink and an ablative surface, thus protecting the basic foam system throughout boost.



SEE PARA 15.2.2.47 FOR TEST DESCRIPTION

SURFACE TEMP F	NO. OF CYCLES (~) AND STRESS LEVEL (KSI)	RESULTS
RT	PRELOAD 5 KSI 1~ AT 51.3	PASSED
-17 -105	3~ AT 34.2 3~ AT 51.3	PASSED

Figure 6.1.8.2-3. Ramp Core Vertical Cork Specimen 5B-3

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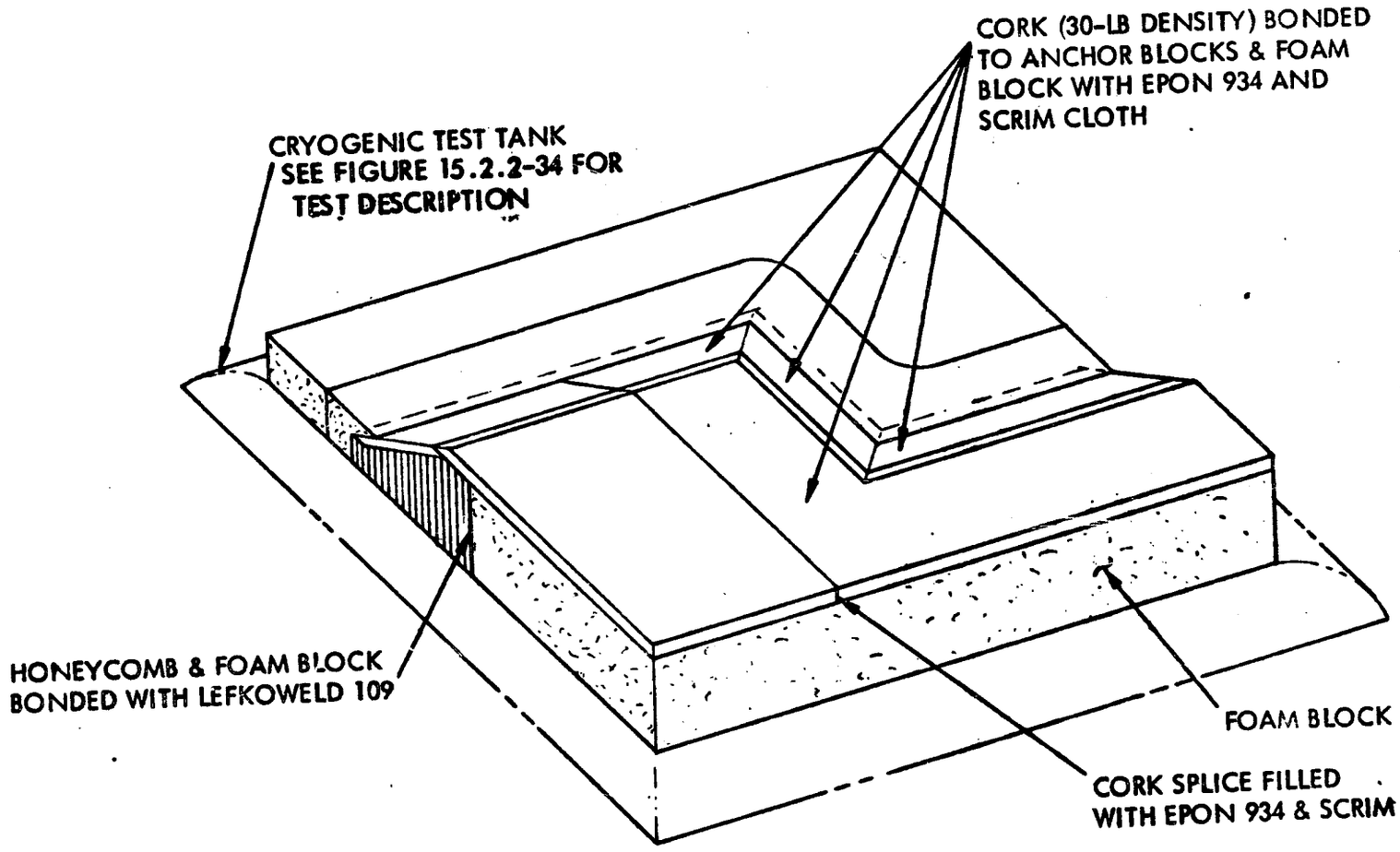

Figure 6.1.3.2-4. 30- by 30-Inch Test Tank Specimen

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Using 0.25 inch of cork bonded to 2.2 inches of foam at the point of maximum heating, the maximum surface and cork-foam bondline temperatures obtained are 790 F and 232 F, respectively. This indicates a possible overtemperature (the cork-foam bondline temperature is limited to 200 F). There are two other regions where an overtemperature occurs, but the regions are small, a total of 5 square feet. All other areas of the S-II do not exceed a bondline temperature of 200 F before 200 seconds of S-IC/S-II boost.

Two cork densities were analyzed. They were 8 and 30 lb/ft^3. With a 0.02-inch fiberglass phenolic cover over the 8 lb/ft^3 cork, the maximum surface and cork-foam bondline temperatures during an S-II mission were found to be 717 F and 318 F, respectively. Corresponding values for 30 lb/ft^3 density cork are 600 F and 245 F. Without the fiberglass cover, the maximum surface and cork-foam bondline temperatures for 8 lb/ft^3 cork were 784 F and 307 F. Corresponding values for the 30 lb/ft^3 cork are 650 F and 237 F. The cork thickness used in the variable density analysis also was 0.25 inch. The only area where cork is mechanically attached is between the systems tunnel flanges and the foam to provide an erosion barrier for the foam adjacent to the tunnel. The bonded cork analysis indicates that the maximum surface temperature in this area is 384 F and the maximum cork-foam bondline temperature is 133 F. The temperature of the system tunnel fasteners is estimated to be 705 F. The heat flux from the fasteners to the LH_2 tank is 12 Btu/hr/bolt.

6.1.8.4 Structural Performance

Significant factors affecting the structural integrity of this insulation system are:

a. This insulation system utilizes organic materials which exhibit a viscoelastic behavior different from the elastic behavior of metals. The stress analysis of organic materials is discussed in Section 8.0.

b. The thickness of the adhesive layers must be properly controlled to insure proper bonding between the rail assemblies, tank wall, and cork.

6.1.8.5 Materials and Processes

a. Materials:

1. Foam: Two-component, flame-retardant polyurethane foam, 2 lb/ft^3 density, for spray application (MB0130-077).

2. Primers:

(a) Adhesive primer, epoxy base resin, two-component, heat curing (MB0120-032).

(b) Adhesive primer, polyester/isocyanate, two-component, room-temperature curing (MB0120-042 Type II).

(c) Epoxy amine corrosion preventive primer, two-component, room-temperature curing (MB0125-047).

3. Adhesives:

   (a) Epoxy adhesive, low-temperature curing, two-component, for use from -250 to +500 F (MB0120-008).

   (b) Modified epoxy, low-temperature curing, two-component, for cryogenic usage (MB0120-023).

4. Adhesive resin: Polyurethane, two-component, low-temperature curing (MB0120-024).

5. Glass fabric, scrim type (MB0135-008).

6. Nylon fabric, woven (MB0135-021).

7. Glass fabric, phenolic resin-impregnated, elevated temperature-resistant (MB0130-004).

8. Honeycomb core, heat-resistant phenolic, 3/8-inch cell, 3.2 lb/ft^3 density (MB0130-014 3/8-3.2).

9. Cork, for use as ablative and thermal insulator, 30 lb/ft^3 nominal density (MB0130-020 Type I).

10. Exterior Coatings:

   (a) Elastomeric polyurethane base coating material, two-component (MB0125-045).

   (b) Vinyl color coat material, single-component (MB0125-046).

b. Process: Installation of this system is controlled by several process specifications. In addition, much process information is presented on the applicable engineering drawings.

   1. Material Storage and Environmental Control: All materials are stored and handled in accordance with the requirements of applicable specifications. Environmental requirements are controlled by the applicable process specification. In general, processing is permitted at temperatures between 60 and 90 F and a maximum relative humidity of 70 percent. Temperature and humidity controls are required for spray foam application. Substrate temperature controls (to avoid water condensation) are required during adhesive bonding.

   2. Bonded-in-place configuration:

      (a) Surface Preparation: When insulating the primary structure with foam, it is usually more expedient to cover the entire structure with insulation and then remove the foam from the areas requiring subsequent detail installation. For this bonded-in-place configuration, a special engineering drawing (V7-531370) specifies areas

of foam removal. The foam is removed with non-metallic cutting tools per MA0606-050. Sufficient excess foam is removed around the periphery of the detail to be installed to facilitate bonding operations.

Metallic surfaces to be bonded must have all primers removed per MA0610-022. Care must be exercised to prevent damage to the tank wall and the adjacent foam insulation by the acid stripper required to remove the primers.

The bare aluminum surface is prepared within 12 hours of actual bonding by etching per MA0610-023. During the time between primer removal and etching for bonding, exposed aluminum must be protected from corrosion per MA0609-007.

(b) Composite Detail Assembly: Honeycomb core (MB0130-014) details are filled with spray foam insulation material (MB0130-077) in accordance with MA0606-050.

Cork insulation (MB0130-020 Type II) is then bonded to the detail per MA0606-061. Cork details are trimmed as required by the engineering drawing. The cork, foam, and core-foam faying surfaces are lightly sanded and vacuumed clean.

Epoxy adhesive (MB0120-008) is prepared and uniformly applied to glass scrim cloth (MB0135-008) to produce a final tape weight of 0.22 to 0.27 gram per square inch. The edges of the cork details which will form a butt joint on assembly are coated with sufficient adhesive to fill the joint gaps. The adhesive pot life and working life are defined and specified in MA0606-061.

The adhesive tape is positioned on the cork detail and the composite assembled under a minimum vacuum of 10 inches of mercury and held under vacuum until a minimum of 6 hours is accumulated at a minimum of 65 F. The adhesive must attain a minimum Shore D hardness reading of 75 prior to application of the coating.

(c) Structural Bonding: Following surface preparation, core-foam composite details are bonded to the structure in accordance with MA0606-050.

Epoxy adhesive (MB0120-023) is combined with glass scrim cloth (MB0135-008) to provide a final tape weight of 0.20 to 0.27 gram per square inch. The adhesive tape is applied to the core/foam composite and a thin butter coat of epoxy adhesive (0.03 gram per square inch maximum) is applied to the aluminum faying surface. The core-foam composite is positioned onto the tank wall under a maximum pressure of 8 psi and allowed to cure 48 hours at temperatures of 60 to 90 F. The first 12 hours of cure must be above 65 F and under pressure.

Joints between adjacent core-foam composites are also bonded with epoxy adhesive and glass scrim cloth in the manner outlined in the proceeding paragraphs. Any bare metal still exposed following the bonding operations must be coated with epoxy amine primer (MB0125-047). The primer should overlap onto the core/foam composite to assure complete coverage of the tank wall.

(d) Foam Insulating: Areas adjacent to the bonded core-foam composites requiring closure are filled with spray foam insulation (MB0130-077) in accordance with MA0606-050. The process is described in Paragraph 6.1.4.5. The foam insulation is trimmed and hand-sanded to the proper dimensions.

(e) Cork Bonding: As required by the engineering drawing, cork insulation is applied over spray foam and unprotected core-foam surfaces. The process is performed in accordance with MA0606-061.

(f) Joints: All cork-to-cork butt joints, with the exception of the joint at the outer mold line transition point (see Figure 6.1.8.1-4) are covered by a wet layup consisting of one ply of nylon fabric (MB0135-021 Type II) and polyurethane resin (MB0120-024) in accordance with MA0605-014 Method I.

The joint at the outer mold line transition point (noted above) is sealed with polyurethane resin (MB0120-024) modified with adipic acid in accordance with processing information specified on the engineering drawing.

Adhesive resin is prepared by combining 0.4 to 0.8 gram of adipic acid with 50 grams at solid curing agent. The mixed curing aged (12.6 to 12.7 parts) is melted at 250 F and combined with 100 parts of base resin. The pot life of the mixed adhesive is 30 minutes. Two uniform seal coats of resin are applied, allowing two hours at 70 F minimum or 24 hours at between 60 and 70 F.

(g) Protective Coating: The insulation surfaces are protected from weather exposure, fungus, and discoloration by application of a polyurethane coating material (MB0125-045) and vinyl top coat (MB0125-046). Three coats of polyurethane and one coat of vinyl top coat are required by MA0608-015.

3. Aerodynamic Fairings and Attach Points: Areas adjacent to aerodynamic fairings which require cork insulation are assembled as shown in Figure 6.1.8-5.

A wet layup consisting of nylon fabric (MB0135-021 Type II) and polyurethane resin (MB0120-024) is applied to the appropriate areas of foam insulation per MA0605-014 Method I.

Cork insulation (MB0130-020 Type I) is bonded to the foam insulation adjacent to the aerodynamic fairing in accordance with MA0606-061.

The cork surfaces are protected from weather exposure, fungus, and discoloration by application of a polyurethane coating material (MB0125-045) and vinyl top coat (MB0125-046). Three coats of polyurethane and one coat of vinyl top coat are required per MA0608-015.

Fairing attach points required by engineering drawing to exhibit the configuration illustrated in Figure 6.1.8.1-6 are processed in accordance with requirements on the engineering drawing.

A "dummy" standoff spacer is inserted on the tank wall prior to spray foam application and cork bonding (described previously) a non-metallic conical trepanning tool is used to remove foam to the tank wall around the dummy insert and the insert is removed. The exposed tank wall is cleaned to remove any foam residue.

A separate spool-shaped stainless steel insert is coated with primer (MB0120-042 Type II) and spray foam-insulated per MA0606-050. The foamed spool piece is subsequently machined to the configuration shown in Figure 6.1.8.1-6.

A special polyurethane based sealing material is prepared by melting solid polyurethane curing agent (MB0120-024) at 250 F, mixing 12.5 parts by weight of the melted curing agent with one part of Z-6040 silane and 100 parts by weight of polyurethane base resin, and adding 15 $\pm$1 parts by weight of 1/32-inch glass fibers. The resin sealer is then applied to the foamed insert, the cork insulation, the foam cavity, and the tank wall and allowed to cure until tack-free.

The insert detail is bonded to the tank wall with polyurethane resin (MB0120-024) per MA0606-039. A bolt, coated with fluorocarbon release agent, is used to secure the insert in to the tank wall by application of 15 to 20 inch-pounds torque.

Exposed cork surfaces are protected from weather exposure, fungus, and discoloration by application of polyurethane coating (MB0125-045) and vinyl top coat (MB0125-046) per MA0608-015.

Fluorocarbon release agent is then applied to the insulation cavity as shown in Figure 6.1.8.1-6. The material is applied by aerosol spray.

4. Mechanically Attached Cork (Figure 6.1.8.1-7): Spray foam insulation is applied to the primed tank wall per MA0606-050 and as described in Paragraph 6.1.4.5.

A cavity, the size and location of which is specified in the engineering drawing, is cut into the foam insulation using nonmetallic tools. A cork detail is cut to the dimensions specified on the engineering drawing. A major portion of the cork surface is coated with polyurethane sealant (MB0125-045). Two coats of sealant are applied per MA0608-015. Provisions for elevated temperature cure are contained on the engineering drawing. That portion of the cork surface which will become a substrate for spray foam insulation is coated with a polyurethane resin (MB0120-024) per MA0606-050.

The cork detail is mechanically attached to the structure and a piece of Teflon tape is inserted to provide a release surface as shown in Figure 6.1.8.1-7. Spray foam insulation (MB0130-077) is then applied to the appropriate cork and foam surfaces per MA0606-050. Non-protected cork and foam surfaces are coated with polyurethane (MB0125-045) and vinyl top coat (MB0125-046) per MA0608-015.

6.1.8.6 Manufacturing

a. Description:

1. Bonded in Place: Cork ramp bonding operations were performed after the LH_2 tank sidewall was spray foamed. Cavities were machined into the foam with high-speed phenolic cutters mounted on a hand-operated router tool. Foam removal from the tank wall was completed using phenolic chisels. The area was then masked and prepared for etching, cleansing, air drying, and bonding.

Rail assemblies were fabricated in the following steps. Foam-filled honeycomb details were trimmed and sanded using templates. Cork sheet details were trimmed and prefit to the foam-filled honeycomb details. Adhesive tape was prepared by applying adhesive to glass scrim cloth. The adhesive tape was positioned on cork detail faying surface and trimmed to size of detail. Cork was installed on foam-filled honeycomb detail in same location as during prefit operation. Vacuum bag was installed and adhesive was cured under vacuum pressure.

The bonding operation of the rail assemblies to the stage is performed in the following steps. Rail assemblies were trimmed and prefit to the LH_2 tank wall. An adhesive tape was prepared by applying adhesive to glass scrim cloth. The faying surface of the rail to be bonded was placed on the adhesive tape and the tape trimmed at the periphery of the part. A butter coat was spread on the appropriate area of the tank to wet the surface. Positioning of the rail on the tank was the same as during the prefit. Vacuum pressure was then applied and the area cured. Trimming and removal of adhesive flashing at edge of bonded rails was then accomplished. Wet layup was installed at butt joint of rails (see Figure 6.1.8.1-2).

Spray foaming operations were accomplished in the following steps. Cavities adjacent to the installed rails were cleaned and primed. Cavities were filled with spray foam per MA0606 050. Foam was trimmed and sanded to fair in with the surrounding foamed areas.

Wet layups were installed in fairing areas (Figure 6.1.8.1-5) as follows: Polyurethane resin was applied to faying surface of foam. Nylon fabric, trimmed net, was applied to coated area of foam. An additional coat of resin was applied to fabric and air inclusions and excess resin rubbed out.

Flat cork sheets were installed as follows. Adhesive tape was positioned on the cork detail faying surface and scrim trimmed to the size of the detail. Cork was positioned over the foam in the same location as during the prefit operation. A vacuum bag was installed and vacuum pressure applied. The assembly was allowed to cure while under pressure.

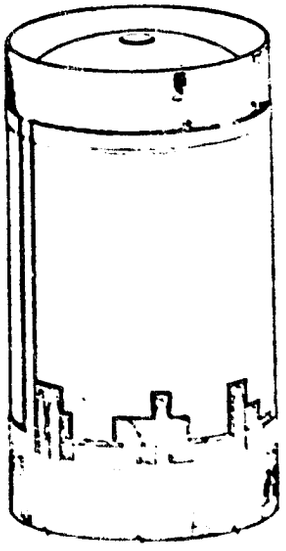
Protective coatings were applied as follows. Polyurethane resin seal coatings were applied at cork butt joints. Seal and color coat was applied to outer surface.

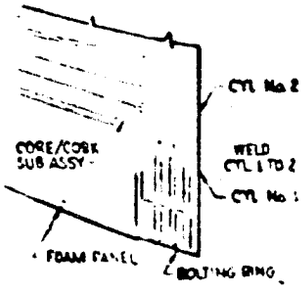
Standoff spacer machining and installation were accomplished as follows. Fairing attach points were recessed with a non-metallic conical trepanning tool and standoffs installed to the configuration shown in Figure 6.1.8.1-6.

Figure 6.1.8.6-1 presents the manufacturing flow diagram.

2. Mechanically Attached: Cork was installed on both sides of the S-II system tunnel which consisted of strips held in place by the tunnel cover fastener screws for the full 1/2-inch by 3-inch length of the LH_2 tank sidewall.

Cork strips were cut to size with a sharp knife, then chamfered on one edge with a router. Holes to match the standoff studs of the systems tunnel were drilled in the cork strips with a special tool incorporating adjustable tooling bushings. After holes were drilled and the cork hand-sanded, two coats of sealant were applied with a nylon bristle brush and cured for 24 hours between each coat. Cork strips were color-coated and allowed to cure. After cure they were installed in their respective locations with a temporary tool simulating the system tunnel cover. In the final assembly station, after checkout of operations, the systems tunnel cover was installed with mechanical fasteners through the cork into the tank completing the attachment. Figure 6.1.8.6-2 is the manufacturing flow diagram of mechanically attached cork.



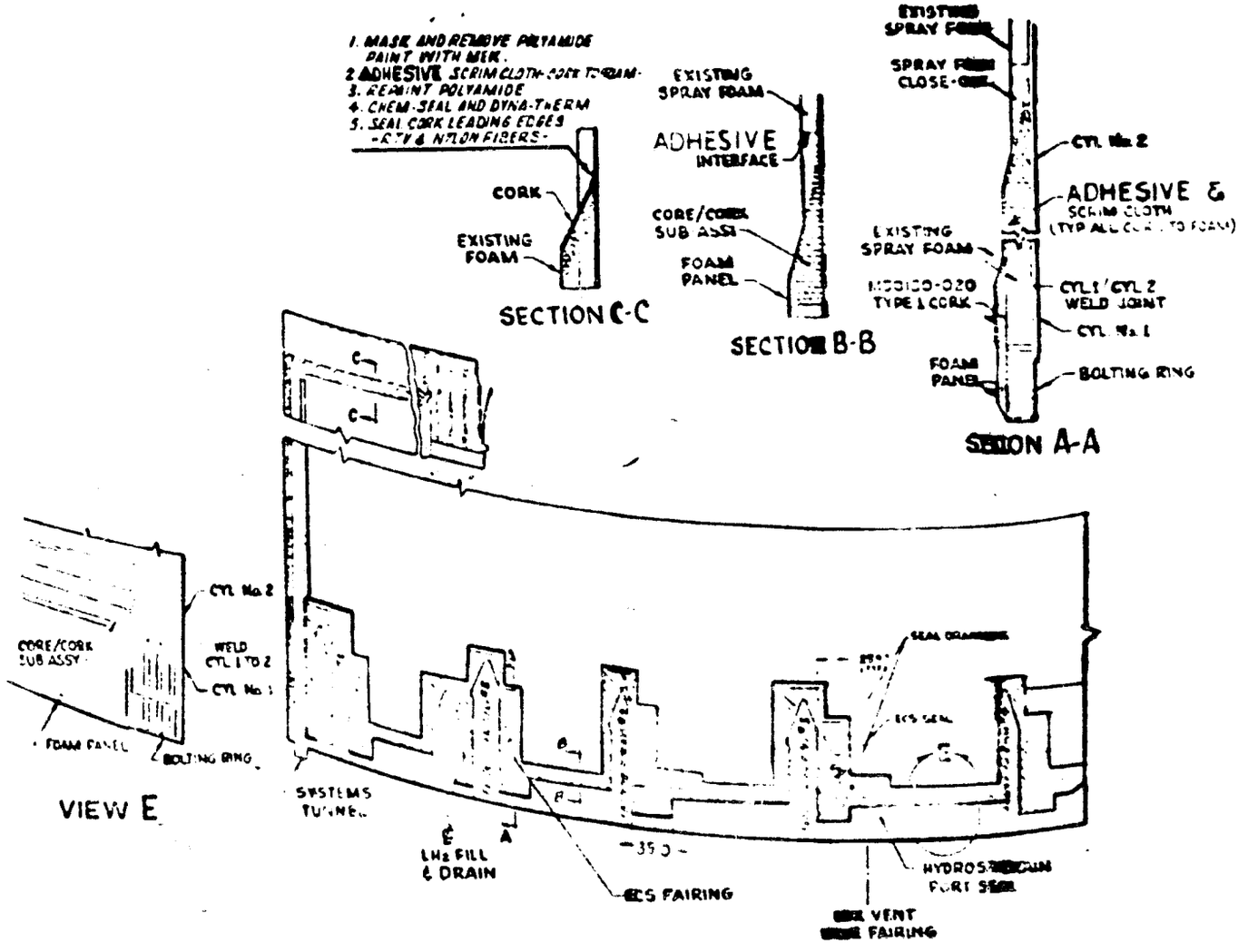


VIEW E

AREAS C

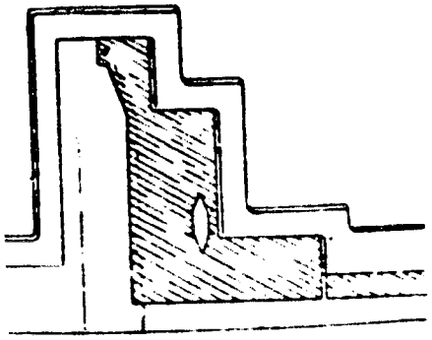
FOLDOUT FRAME 1

C4

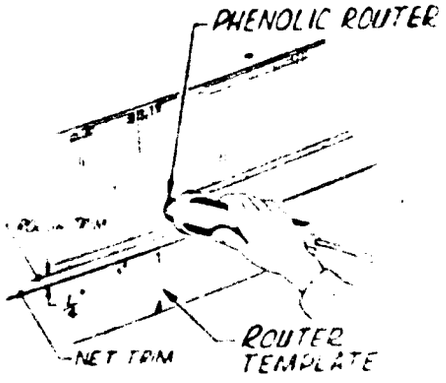


AREAS OF CORK INSULATION

FOLDOUT FRAME 2



● APPLY GUIDE TEMPLATES



● COMPLETE ROUGH TRIM

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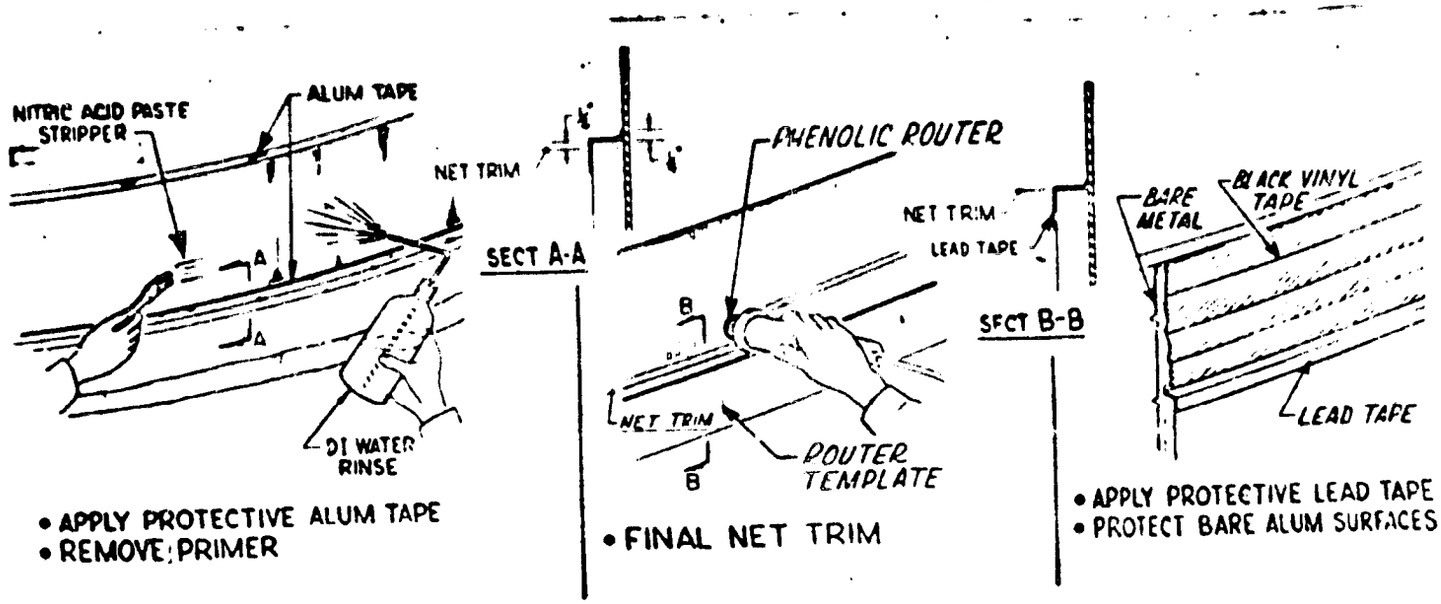

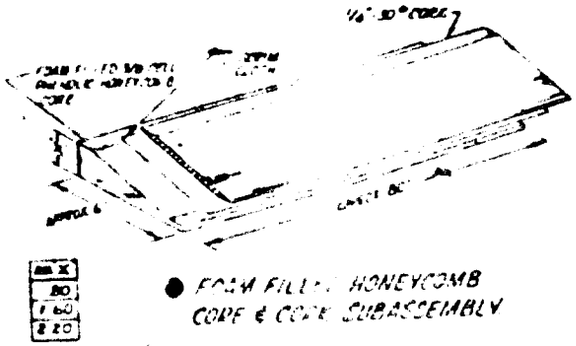

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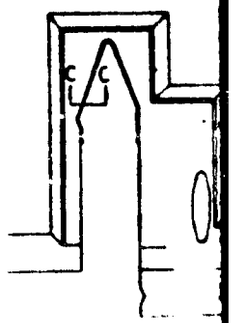
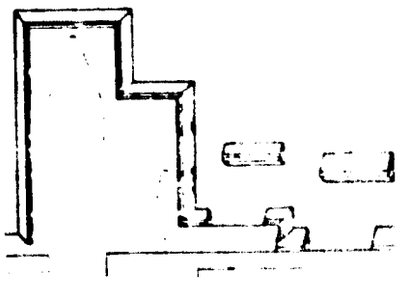
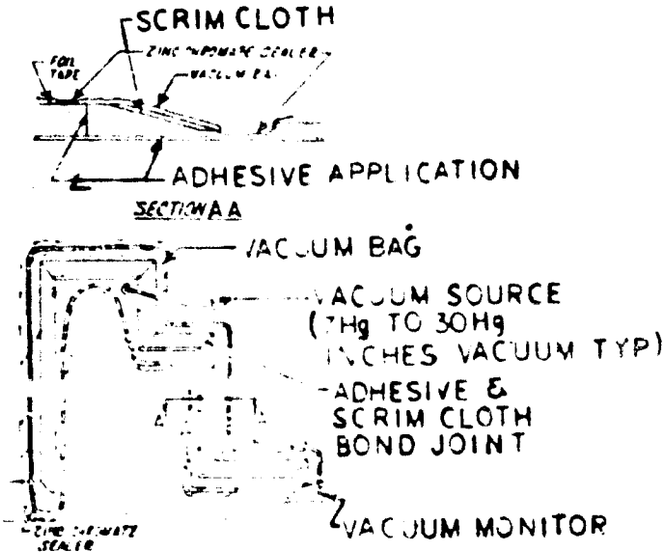


● PREFIT FLAT



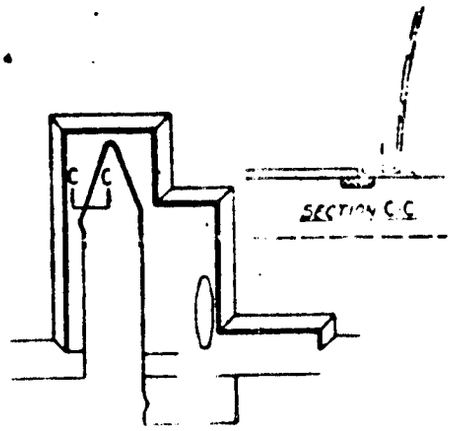
● PREFIT CORE/CORK RAMP SUBASSEMBLIES.



● BOND CORE/CORK RAMP SUBASSEMBLIES.

PREFIT & BONDING

FOLDOUT FRAME 5



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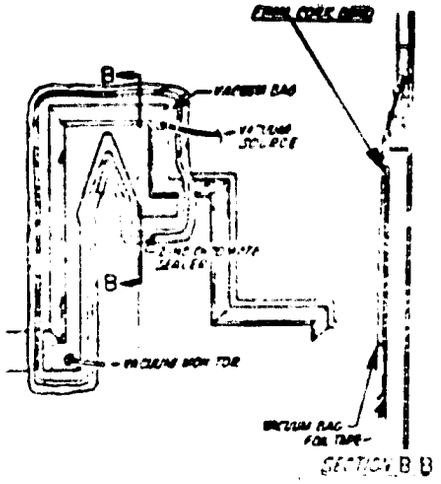
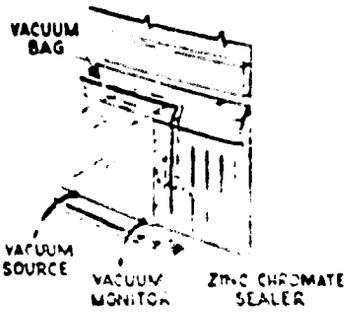
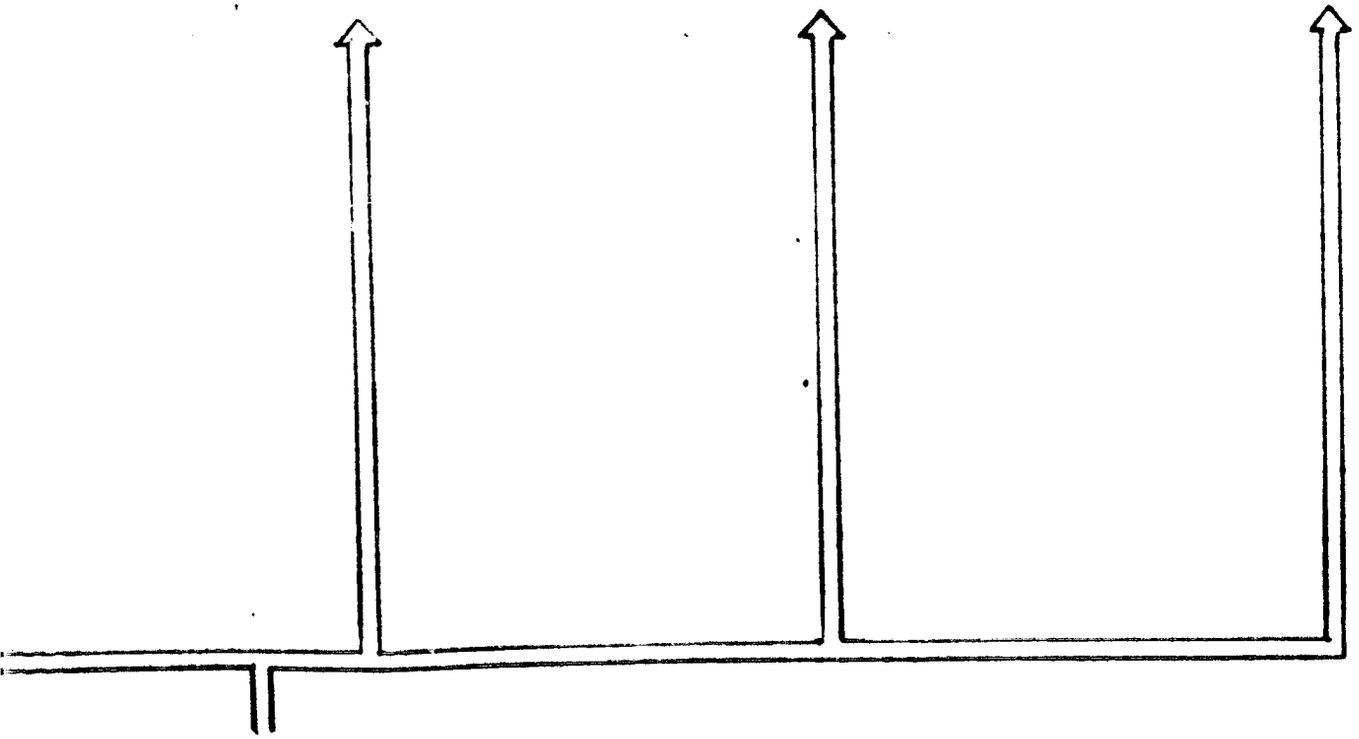


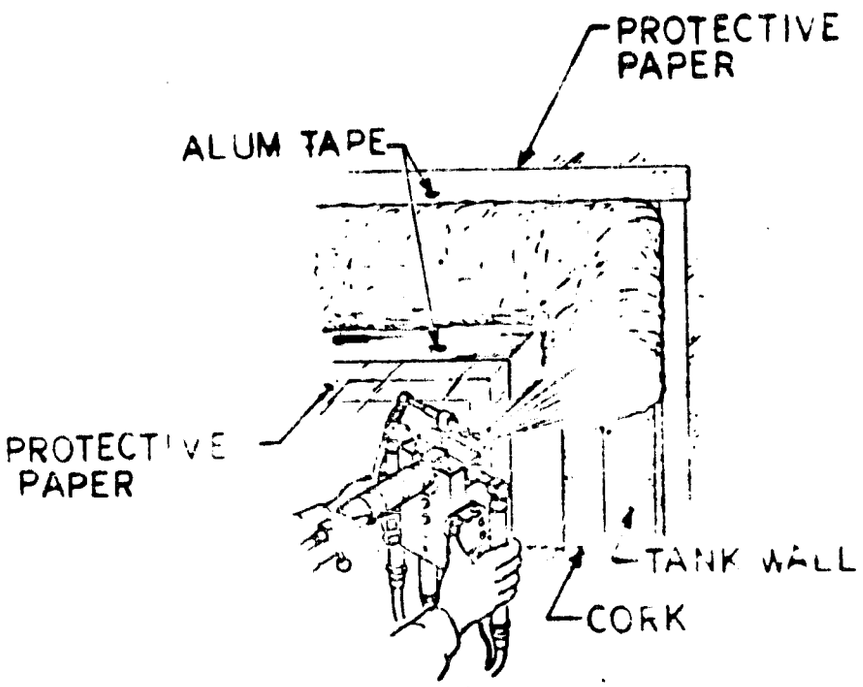
● BOND FLAT CORK AREAS



● BOND FOAM PANELS



BONDING OPERATIONS



SAND PAPER

ROUG

TYPICAL SPRAY FOAM APPLICATION IN CLOSE OUT AREA

APPLICATION OF SPRAY FOAM INSULATION

FOLDOUT FRAME 7

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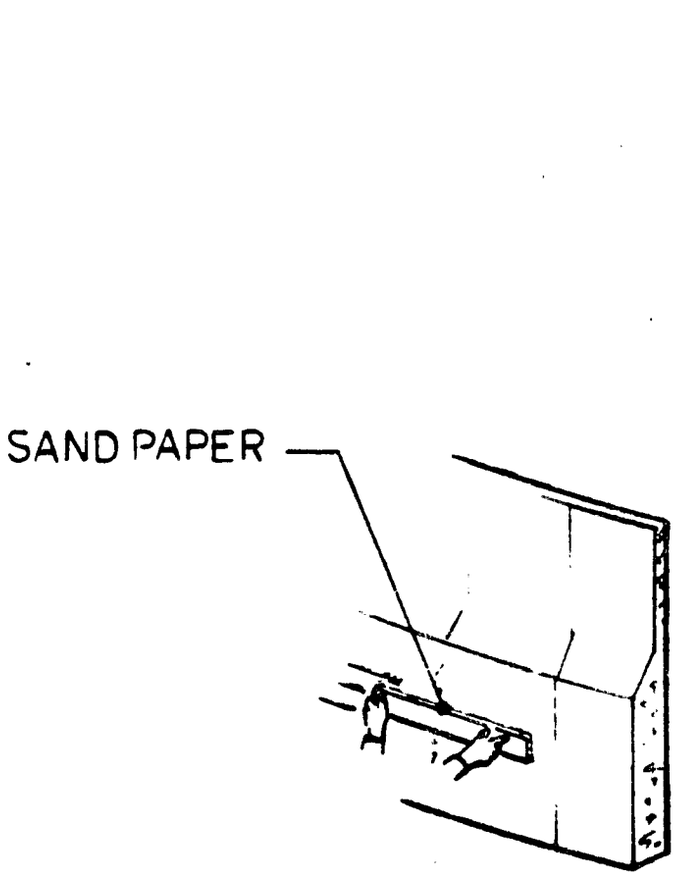
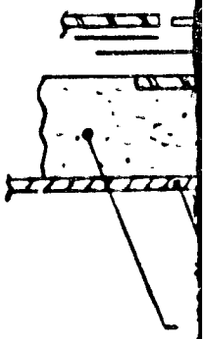
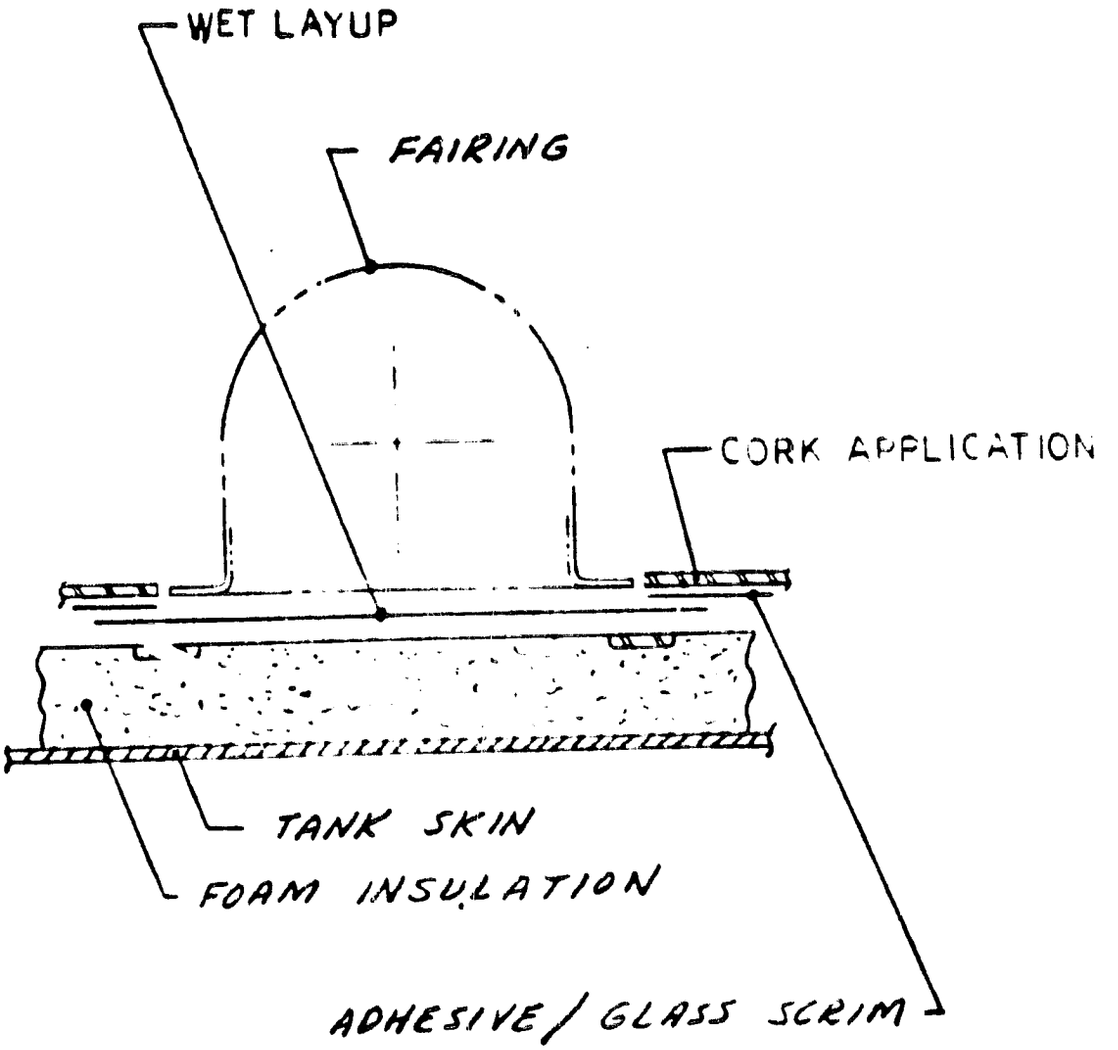


ROUGH HAND SANDING





CORK APPLICATION UNDER FARING

FOLDOUT FRAME 9

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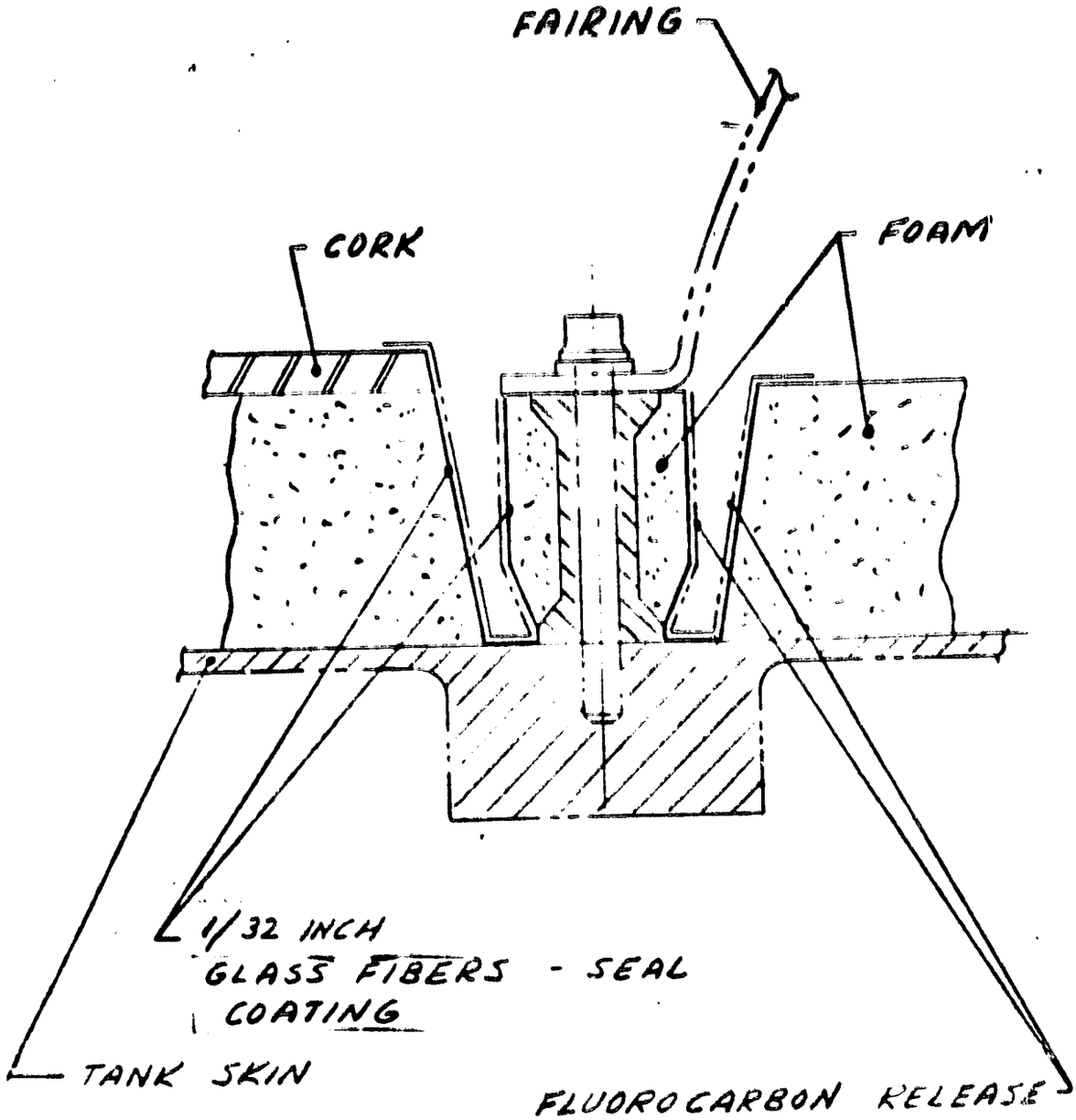

STAND-OFF INSTALLATION

STAND OFF SPACER INSTALLATION

FOLDOUT FRAME 10

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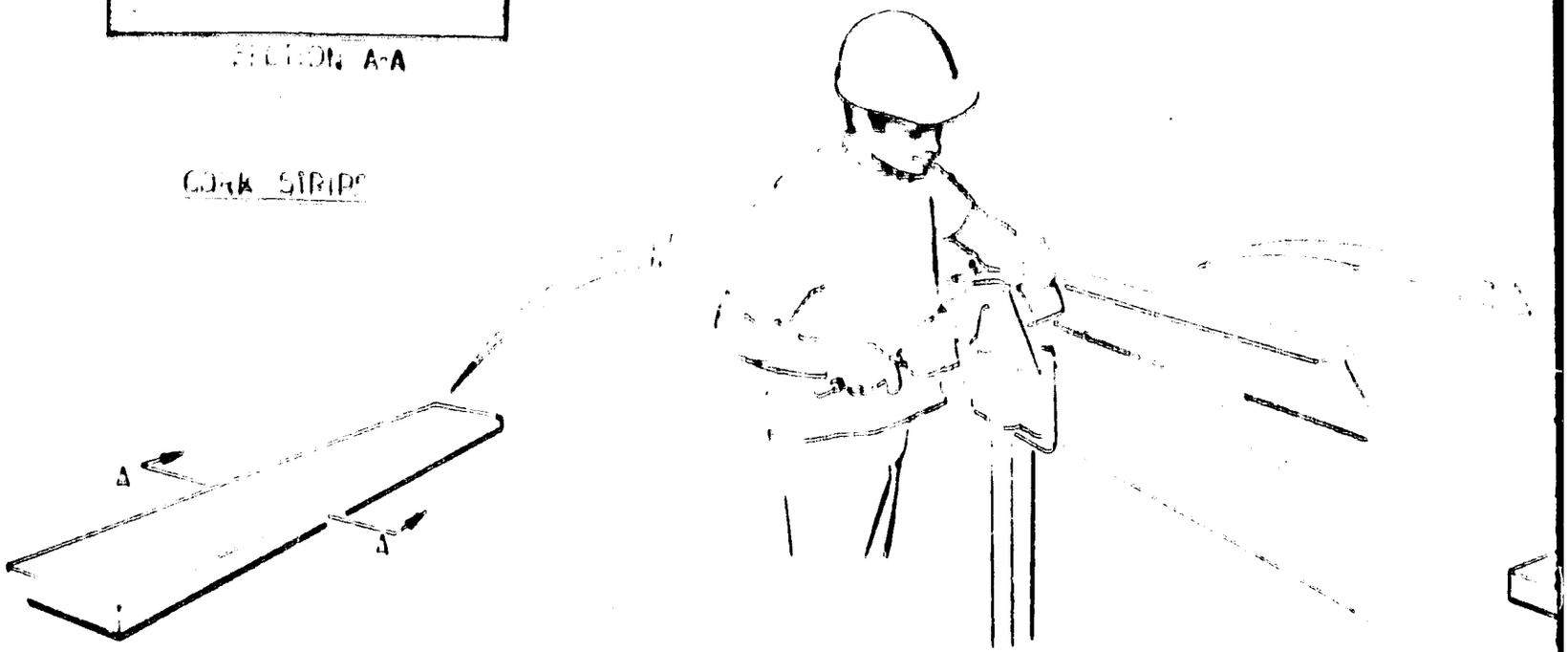
Figure 6.1.8.6-1. Cork Bonded to Foam

FOLDOUT FRAME

REPRODUCIBILITY OF THE ORIGINAL PAGE

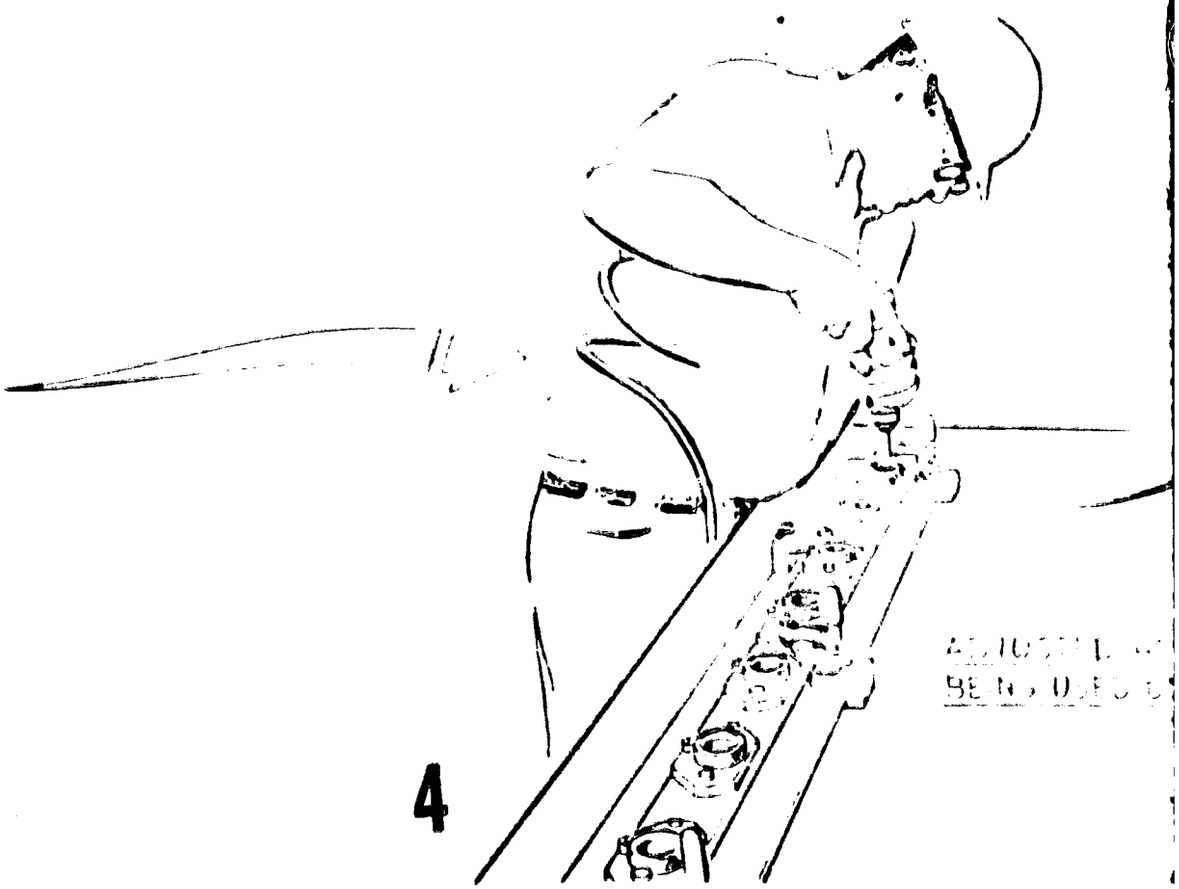
SECTION A-A

CORK STRIPS



1

MACHINING EDGE OF CORK STRIPS



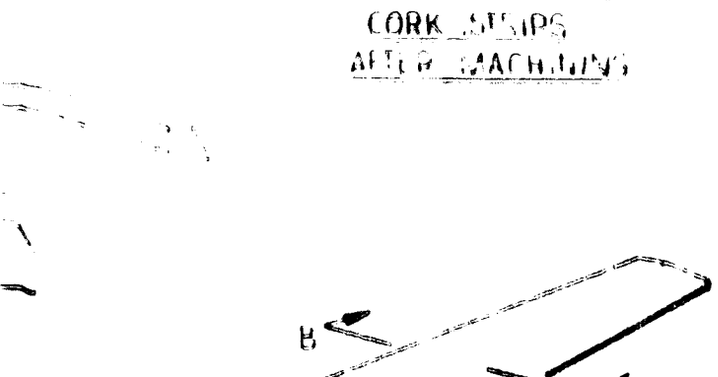
4

FOLDOUT FRAME

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

SECTION B-B

CORK STRIPS
AFTER MACHINING

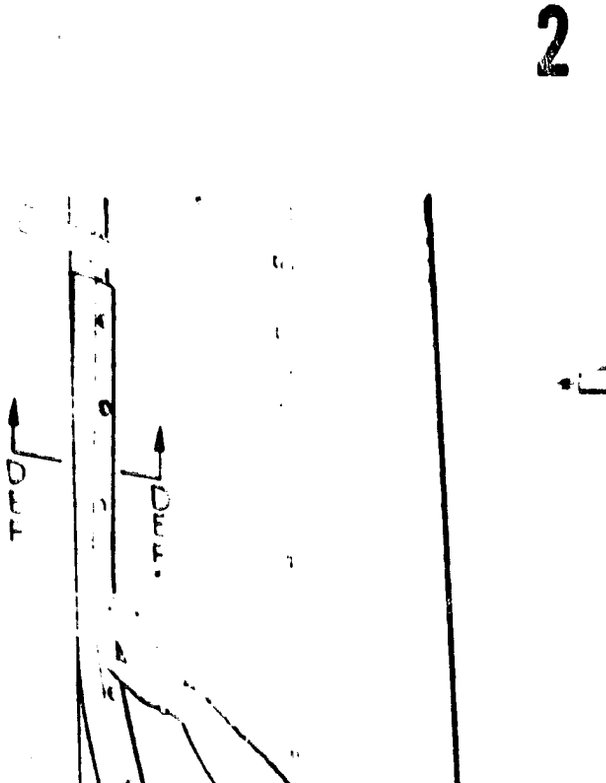


4

2

TYPICAL ROUTER CUT
SHIP WITH ROUTER

ADJUSTABLE HOLE CUTTER
BEING USED ON FOAM STRIP



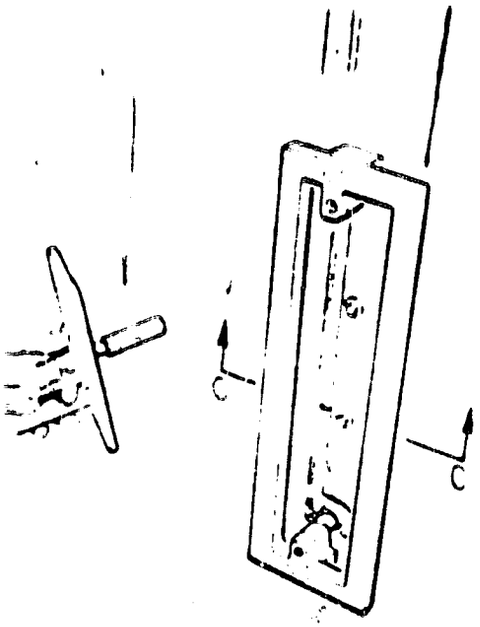
5

NARMCO

SECTION B-B

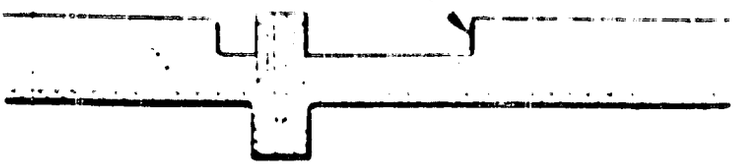
* THEN SEAL CUT AREAS WITH CATEX AND EPOXY

FOLDOUT FRAME 2



℄ TUNNEL

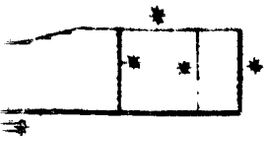
NSTALL TEFLON TAPE
(1 SIDE ONLY)



SECTION C-C, AFTER MACHINING

ROUTER GUIDE PLATE ON
WITH ROUTING IN PROGRESS

NARMCO



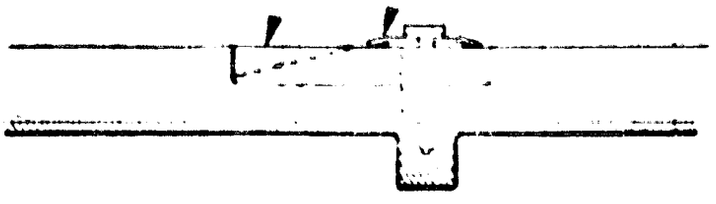
SECTION D-D

SEALCOATS
AS INDICATED
ENDS

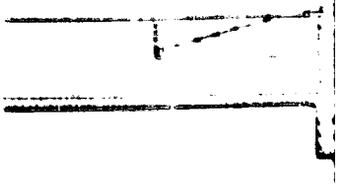
U-CHANNEL FOR HOLDING
CORE DETAILS DURING
SPRAY FOAMING
(TEMPORARY TOOL)

℄ TUNNEL

SPRAY FOAM



SECTION E-E



SECTION
SYSTEMS T
IN POSITIO

FOLDOUT FRAME 3

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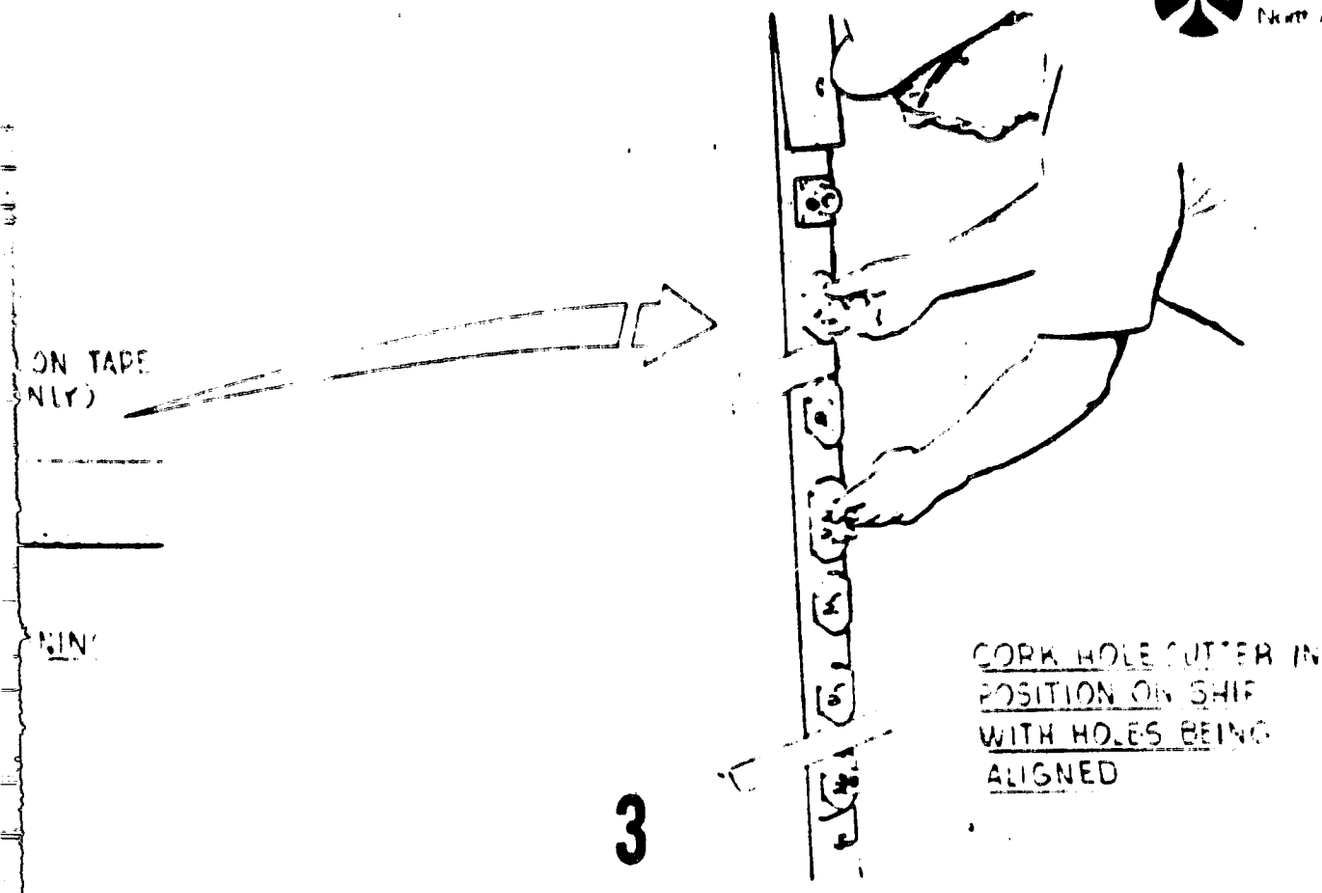


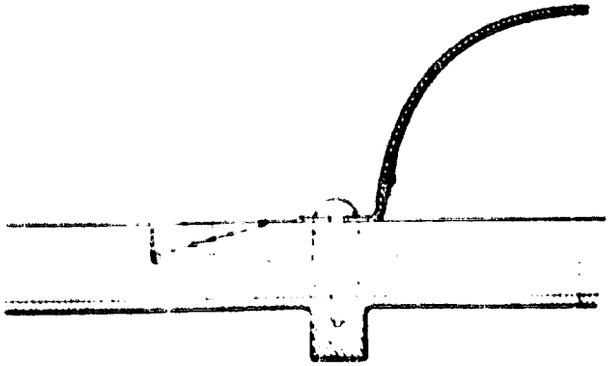


Figure 6.1.8.6-2. Cork Mechanically Attached to Foam

b. Tooling and Equipment: Tooling consisted of router-adapted fixtures for each of the fairing configurations, cork ramp bevel fixtures, grooving tools for cork flanges, trim tool for fairing attach configuration, a circumference trim tool around tank, a slot router tool, special phenolic cutters, rail and block templates and trim tools, and trim skates.

Equipment consisted of router motors, vacuum source, and system of hoses, gages, fittings, and regulators; caulking guns; refrigeration for "B" stage wet layup laminates; spray foam gun and mixing nozzle assembly; foam depth proximity device; protective covers; holding fixtures; mechanical saws and related attachments; and scissors, knives, depressors, paddles, towels, tape, polyethelene film, containers, bleeder cloth, and kraft paper.

6.1.8.7 Quality Assurance

The majority of the quality control aspects of the insulation configuration shown in Figures 6.1.8.1-1 through 6.1.8.1-7 are directly related to spray-on-foam-insulation and are established in Paragraph 6.1.4.7. Areas unique to cork as a thermal insulator are depicted in Figure 6.1.8.1-4. Specifically, the quality control techniques covered in this section of the report are associated with the structural bonding of the rail assemblies to the tank wall and the bonding of exterior cork to the composite.

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control:

1. Structural Rail Bonding (MA0606-050):

(a) Prefit: In cases where the rail assembly traversed a weld bead or other surface irregularity, the rail was contoured to assure uniformity of the subsequent bond line. An impression check was performed using a 10-mil sheet of Mositex rubber. A uniform impression was verified when minimum bonding pressure was applied.

(b) Surface Preparation: Surfaces were etched and controlled per MA0610-023 with the attendant verification of proper pH and water break-free surface.

(c) Bond Line Thickness Control: The adhesive (MB0120-023) plus glass scrim cloth (MB0135-008) was verified by sample weight to be within 0.20 to 0.27 gram per square inch. In addition, the total adhesive weight was verified to be between 0.20 and 0.30 gram per square inch by controlling the adhesive applied

directly to the metal substrate (the "butter coat"), to a maximum of 0.03 gram per square inch. This was accomplished by calculating the bond area and the determination of applied adhesive by weight loss in the adhesive container.

(d) Process Verification Test Coupons: Lap shear strength test coupons were fabricated simultaneously with the production bonding operation. Final acceptance of the production rail assembly was based on the lap shear strength results.

2. Sheet Cork Bonding (MA0606-061):

(a) Bond Line Thickness Control: The adhesive (MB0120-008) plus glass scrim cloth (MB0135-008) was verified by sample weight to be 0.22 to 0.27 gram per square inch.

(b) Visual Inspection: Subsequent to the vacuum bag bonding operation, the cork was visually inspected for apparent voids and overall cork integrity. The chances for bond line voids were extremely negligible because the fact the cork was cured under vacuum. The cork was sufficiently porous to remove entrapped air during the cure cycle.

(c) Process Verification Test Coupons: Sample adhesive (MB0120-002) castings were taken from each mix of adhesive employed in the production bonding operations. Following cure, each test sample was verified to have reached a minimum Shore "D" hardness of 75.

c. Quality Verification of Final Assembly: Final acceptance of the completed assemblies was based on the inspection points established in Paragraph 6.1.8.7-b. Subsequent visual inspection was performed, however, at the Mississippi Test Facility immediately following static firing of the stage.

6.1.8.8 Repair and Maintenance

a. Repair: Repair and rework of discrepant foam insulation is described in Paragraph 6.1.4.8. In-process rework is allowed to bonded cork insulation only to the extent of incompletely filled butt joints per MA0606-061. All other repairs to bonded cork require Material Review Board approval.

b. Maintenance: No special maintenance procedures are required for these insulation systems.

6.1.8.9 Reliability

There was no detailed failure mode effects analysis formulated because of the absence of any obvious first-order failure modes.

6.1.8.10 Safety

a. Fabrication and Installation: This insulation system utilizes a large number of detail parts of different types and kinds. The individuals processing these detail parts are exposed to a greater variety of hazards than if they were to process a single variety alone.

Careful fitting of the insulation detail parts is necessary to insure the integrity of the resulting assembly. Many interfaces are present that would lead to large gaps or voids if these interfaces are not sealed by carefully fitting the parts.

During assembly of this system it is necessary to verify that errors of installation are not covered by later installations. In-process inspection and testing must be used to verify that each portion of the system is sound prior to the installation of the next part.

Additional safety requirements are given in Paragraph 6.1.1.10.

b. Cork Insulation Use: The applied cork is relatively fragile and damage is easily incurred after the installation is complete. When the exterior surface is struck by heavy objects the facing sheet can be delaminated and lead to loss of efficiency. Care should be exercised in the use of cork to insure that no damage to the insulation surface is sustained.

After each cryogenic exposure the exterior surface of the cork insulation should be inspected for damage. Any damage should be repaired and tested prior to another cryogenic exposure.

6.1.8.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The hours consist of fabrication, installation, and assembly effort and are an indicator of its relative cost. Data are not available on these costs.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 4 weeks.

Subassembly - 1 week.

Installation - 6 weeks.

Checkout - 1 week.

c. Weight: The total as-installed weight (cork and honeycomb rails) is 1.62 lb/ft^2 broken down as follows:

1. Honeycomb, 3/8 cell, 3.2 lb/ft^3, 1.6-inch thick (MB0130-014) - 0.426 lb/ft^2

2. Foam, 1.6-inch thick (MB0130-077) - 0.267 lb/ft^2
3. Adhesive/scrim (MB0120-008/MB0135-008) - 0.071 lb/ft^2
4. Cork, 0.25-inch thick (MB0130-020 Type 1) - 0.625 lb/ft^2
5. Seal coat (MB0125-045) -.072 lb/ft^2
6. Color coat (MB0125-046) - 0.024 lb/ft^2
7. Primer (MB0125-047) -0.005 lb/ft^2
8. Adhesive/scrim (MB0120-023/MB0135-008) - 0.126 lb/ft^2
9. Primer (MB0120-042 Type II/MB0120-032) - 0.003 lb/ft^2

d. Thermal Performance: The Q of this system is 80 btu/hr/ft^2. The ρK of this system is 0.076 btu/lb/hr-^{o}F-ft^4.

6.1.9 Polyimide Erosion Barrier - Mechanically Attached

6.1.9.1 Description

A polyimide panel system was proposed as an erosion barrier over spray-on foam insulation on the INT-21 and the Expendable Second Stage (ESS) studies (SD 70-684). The outer polyimide facing sheet protects against aerodynamic shear and the space between facing sheets provides thermal resistance to aerodynamic heating. In localized protuberance-influenced regions, the thermal resistance would be increased by the addition of an ablator to the outer facing sheet.

The erosion barrier concept and related details are shown in Figures 6.1.9.1-1 through 6.1.9.1-4. Rigid panels, utilizing lightweight sandwich construction, are made of heat-resistant phenolic (HRP) honeycomb core with polyimide facing sheets. The panels are fabricated with a smaller radius of curvature than the radius of the tank to assure edge clampdown between adjacent panels. A panel joint with overlap is shown in Section A-A. Detail B shows the slotted hole concept selected for retaining the panels. Orientation of the slots allows for axial and circumferential tank movement and expansion and contraction of the panels. Section C-C shows a concept for attaching the panels to the tank structure.

6.1.9.2 Application

a. Utilization: The polyimide sandwich barrier has many applications where a combined insulation and erosion barrier is required. The polyimide material has good high-temperature properties, is nonflammable, and can be fabricated according to existing processing procedures. The system as designated for the advanced S-II boosters allows attachment over the foam insulation either in manufacturing or in the field.

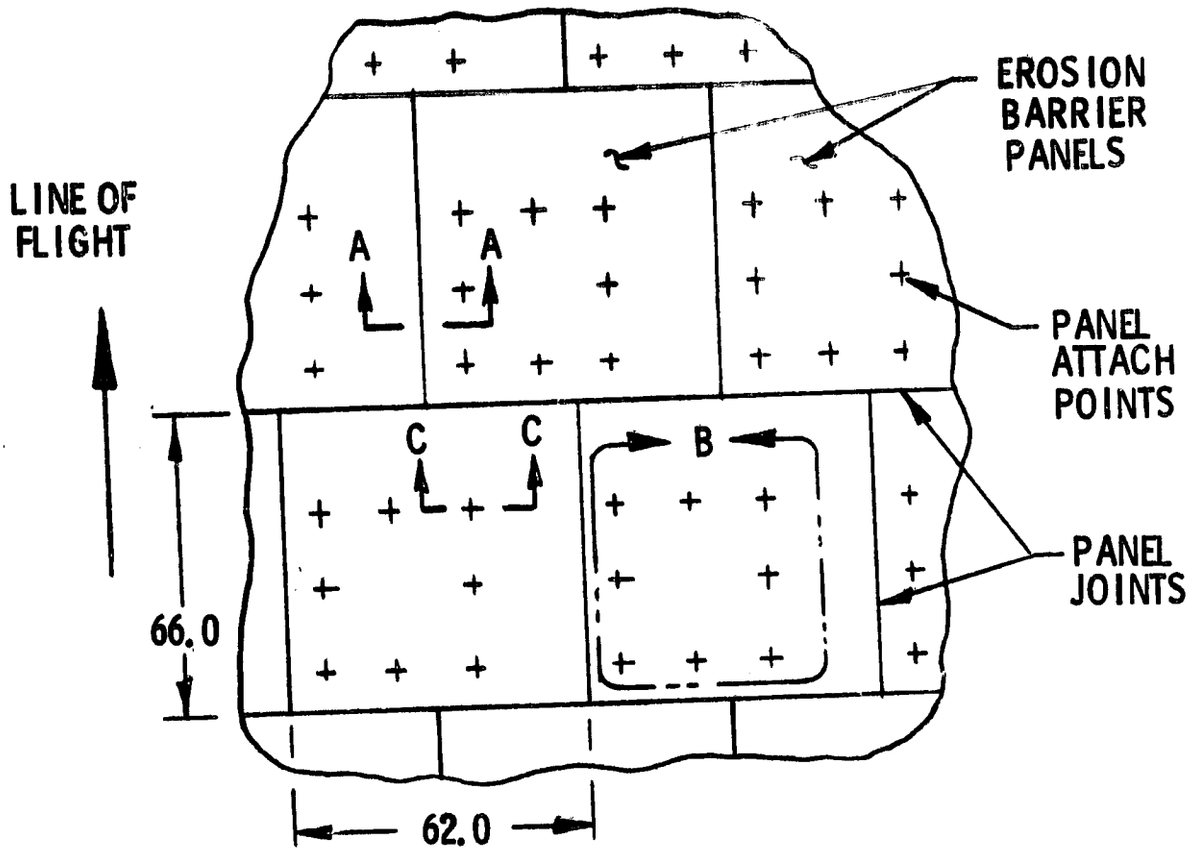


Figure 6.1.9.1-1. Erosion Barrier Concept - View Looking Inboard at LH_2 Tank Sidewall

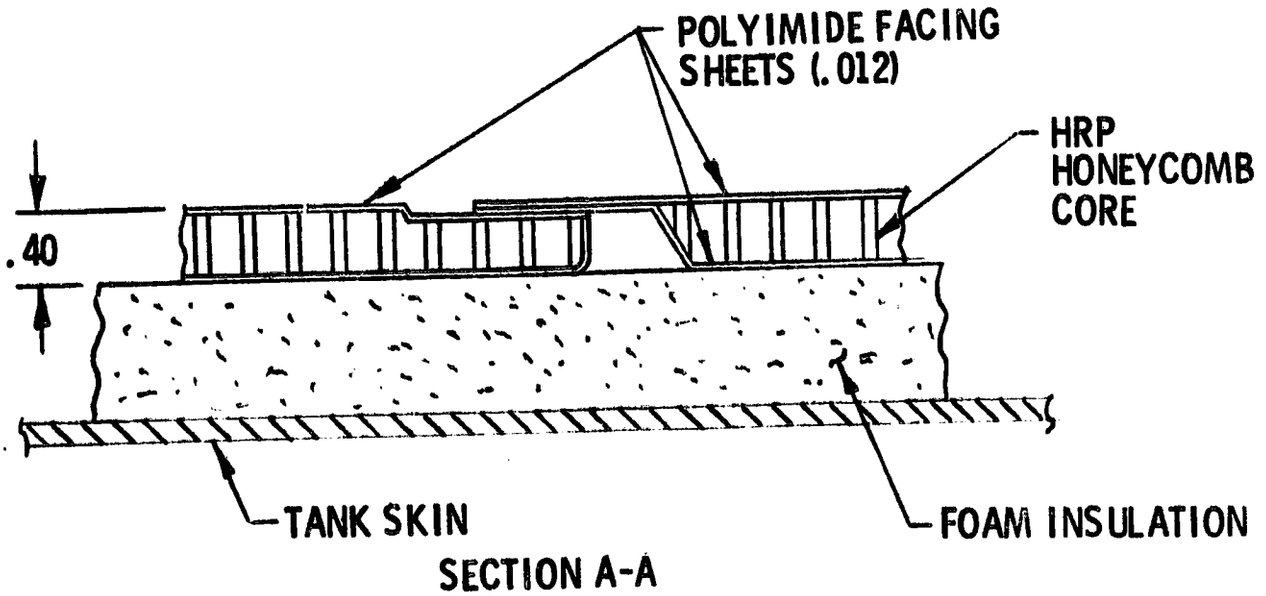
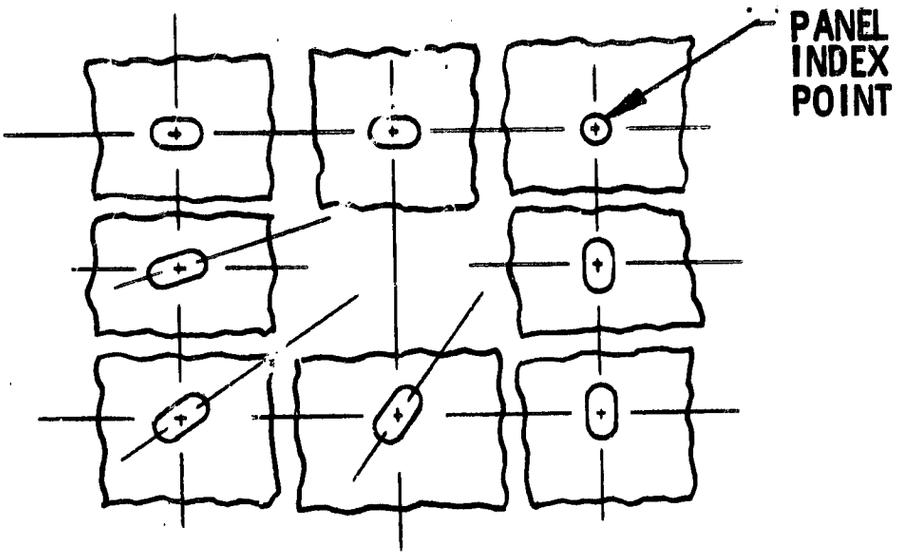
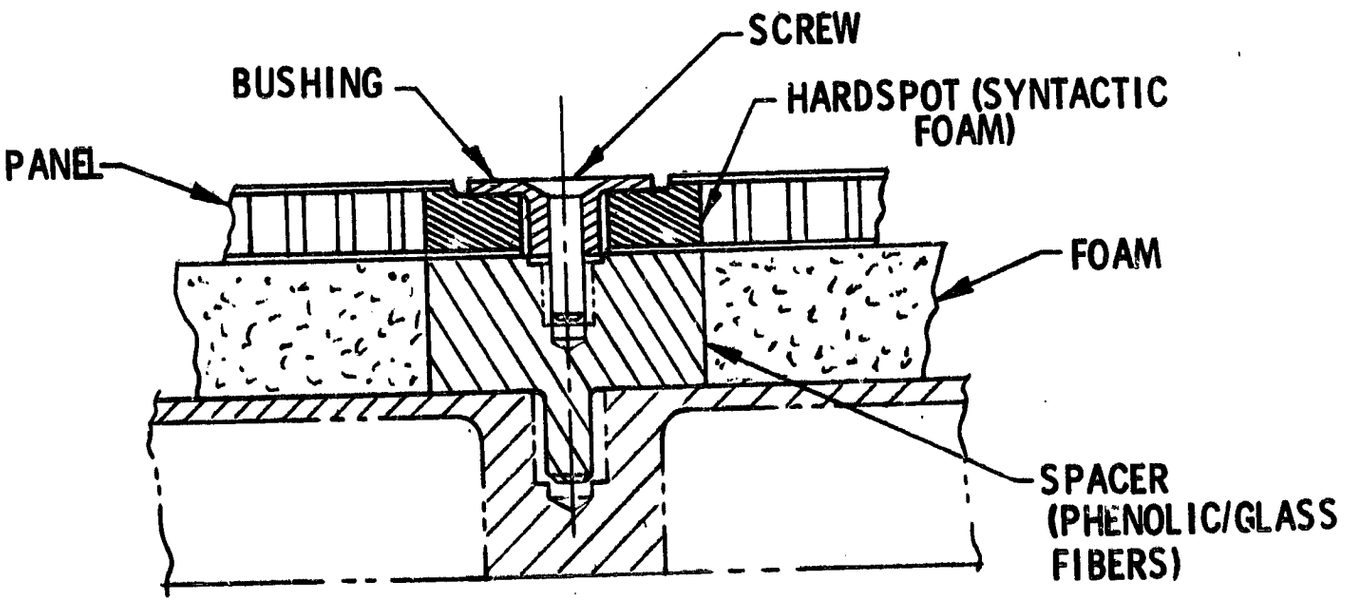


Figure 6.1.9.1-2. Panel Detail



DETAIL B

Figure 6.1.9.1-3. Panel Attachment Pattern



SECTION C-C

Figure 6.1.9.1-4. Panel Attachment

b. Performance Characteristics: Performance characteristics of this system have been obtained through limited laboratory tests and analysis (SD 70-684). The data indicate that the system is feasible and would provide adequate protection for launch stages.

c. System Limitations: Limitations on the system are (1) on the panel dimensions compatible with the aerodynamic forces (shear, flutter, and Δp across panel) and (2) the maximum temperature capability of the polyimide materials. Test data and analysis indicated a limitation on the panel size of roughly 60 inches by 60 inches by 5/16 inches with eight attachment points. The maximum temperature capability was determined in aeroheating type tests to be 1000 F.

d. Design Problems: The program conducted for evaluation established feasibility of the system. The nature of the problems experienced were primarily those associated with a laboratory program and were not considered as design problems.

e. Verification: No verification program was conducted. Limited test was done as described in SD 70-684 to establish feasibility.

6.1.9.3 Thermal Performance

The important thermal performance characteristic of the polyimide sandwich panel (mechanically attached over foam as an erosion barrier) is that it be capable of withstanding the heating rates experienced during boost of the INT-21 configuration.

The basic assumptions made were: (1) external surface emissivity equal to 0.9 and absorbtivity equal to 0.3; (2) aerodynamic heating rate multiplying factors (MF) due to MDAC Space Station protuberances (Saturn V basic design protuberance regions); and (3) radiation barrier conductivity equivalent to air. Saturn V heating rates were assumed because INT-21 heating rates were not available at the time the analysis was performed. The conductivity of the honeycomb was assumed to be the same as the conductivity for air since there was insufficient time for blow-down and outgassing during the subject flights.

The maximum surface temperatures obtained occurred in regions of the multiple protuberances with a radiation barrier in the honeycomb. The temperatures of the exterior and interior facing sheets were 675 F and 322 F, respectively. Without the radiation barrier, the exterior and interior temperatures were 634 F and 552 F, respectively. The maximum surface temperature in the area of the attachment points was 291 F. The upper limit of the polyimide is 1000 F; thus it is clear that even though INT-21 heating rates will be somewhat greater than the assumed Saturn V heating rates, the polyimide barrier will not exceed upper temperature limit during INT-21 boost.

6.1.9.4 Structural Performance

The primary function of this insulation system is to provide thermal protection; it is not intended to be a primary load-carrying structure. However, the insulation system is required to match the deflections and strains of the tank and also is subjected to thermal and pressure loadings. As a result, stresses and strains may be introduced into the insulation system.

Of prime structural importance are the following:

a. Although the insulation system is of lightweight construction, it is not bonded to the tank. Hence, the effects of the dynamic response of the insulation system upon stress levels must be considered.

b. Proper orientation of the slots in the panels, as shown in Figure 6.1.9.1-1, results in relieving the stresses caused by differences in thermal expansion and contraction rates and tank movements.

6.1.9.5 Materials and Processes

The HRP honeycomb-glass/polyimide erosion barrier was not produced in accordance with any material or process specification requirements and, therefore, no completely defined procedures or techniques were established.

6.1.9.6 Manufacturing

No manufacturing information is available.

6.1.9.7 Quality Assurance

This design did not reach production status during the course of the Saturn S-II program. No quality control procedures were therefore established for the total insulation system. Quality assurance provisions for the foam portion of the composite are included in Paragraph 6.1.4.7.

6.1.9.8 Repair and Maintenance

No standard repairs or maintenance procedures were developed.

6.1.9.9 Reliability

No failure mode effects analysis or other reliability information is available.

6.1.9.10 Safety

Hazard analyses have not been conducted and insufficient operational experience has been accumulated on this insulation system to formulate safety requirements.

6.1.9.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The hours consist of fabrication, installation, and assembly effort and are an indicator of its relative cost. No data are available for this system.

b. Schedule: The schedule flow times for this insulation system are not available.

c. Weight: The total as-installed weight is 0.436 lb/ft^2 broken down as follows:

1. Foam 1.38-inch thick (MB0130-077) - 0.231 lb/ft^2
2. Honeycomb, 2.2 lb/ft^3, 0.375-inch thick - 0.007 lb/ft^2
3. Polyimide facing sheets, 0.012-inch thick - 0.198 lb/ft^2

d. Thermal Performance: The Q of this system is 80 $Btu/hr/ft^2$. The ρK of this system is 0.065 $Btu/lb/hr-°F-ft^4$.

6.1.10 Multi-layer Insulation, Flow-through Purge

6.1.10.1 Description

Insulation systems for long-term storage and reusable cryogenic systems for orbital applications require the use of multi-layer insulation (MLI) to provide thermal insulation for minimum propellant boiloff losses. To attain the lowest thermal transport across the insulation, the layers of MLI should be in minimum contact with one another and surface interruptions or penetrations should be kept to a minimum. In a vacuum, then, the major heat transfer mechanism would be thermal radiation which is controlled by the surface emittance of the layers of MLI.

The approach to producing an acceptable MLI system entails layer isolation through the use of separators (nets, foams, bonded tufts) or through the distortion of the surfaces (crinkling or embossing) to minimize layer contact area. An MLI developed under a Saturn S-II advance technology study (SD 71-263) consisted of singly aluminized Mylar sheets having a random embossed pattern with 2 percent of the area perforated. The material was trade-named NARSAM-2 (North American Rockwell singly aluminized Mylar). The thermal conductivity of the MLI is affected significantly with change in layer density (stack height of layers of the embossed film) and with change in contact area between layers. These parameters are largely determined by the embossment pattern (number and shape of peaks) which must therefore be closely controlled.

NARSAM-2 was installed on a 105-inch-diameter cryogenic test tank which was supplied by and will be tested at MSFC. The MLI design, including the supporting posts and membrane, are shown in Figure 6.1.10.1-1. The insulation system includes an internal and external preconditioning system for MLI drying prior to use. The preconditioning or drying process reduces outgassing and thus aids in early attainment of an effective vacuum in the MLI. The performance of the MLI is therefore improved in the early portion of a mission. The inner purge system consisting of an upper and lower manifold with connecting tubes is shown in Figure 6.1.10.1-2.

The embossed aluminized Mylar has a service temperature with an upper limit of 140 F. In applications where higher temperatures will be encountered (+300 F maximum) a goldized polyimide (Kapton) may be used. However, the Kapton is more expensive, the embossment process for the polyimide substrate has not been developed, and batch processing for gold metallizing is not yet available.

6.1.10.2 Application

a. Utilization: An insulation system of this type can be utilized for insulating any cryogenic storage system for use in space. It is particularly applicable where the system will be returned to earth for subsequent reuse. It can also be used to limit radiant heat transfer within a dewar tank system.

b. Performance Characteristics: Tests have not yet been conducted on this system; however, predicted thermal conductivity for the system using NARSAM-2 material is shown in comparison with other MLI systems in Figure 6.1.10.2-1 (SD 71-263). Predicted density-conductivity (pk) factor is shown in Figure 6.1.10.2-2. The installed insulation system weight, LH_2 boiloff weight, and total insulation system plus boiloff weight are shown in Figures 6.1.10.2-3, -4, and -5.

c. System Limitations: The principal limitations for a system of this type are related to the materials selected for the reflective shields. The aluminized Mylar system is the lightest, simplest to produce, cheapest, and has been used more than other types. It is limited to upper temperature of 140 F, where pressure is experienced across the MLI. In addition, aluminized Mylar is susceptible to corrosion from moisture intrusion; however, this can be eliminated by proper purge system design.

Kapton is heavier than Mylar and can be used where temperatures up to 300 F may be experienced. The reflective surface can be aluminum but is generally gold. Gold is selected because of its inert chemical properties.

d. Design Problems: Design problems and solutions are summarized in Table 6.1.10.2-1.

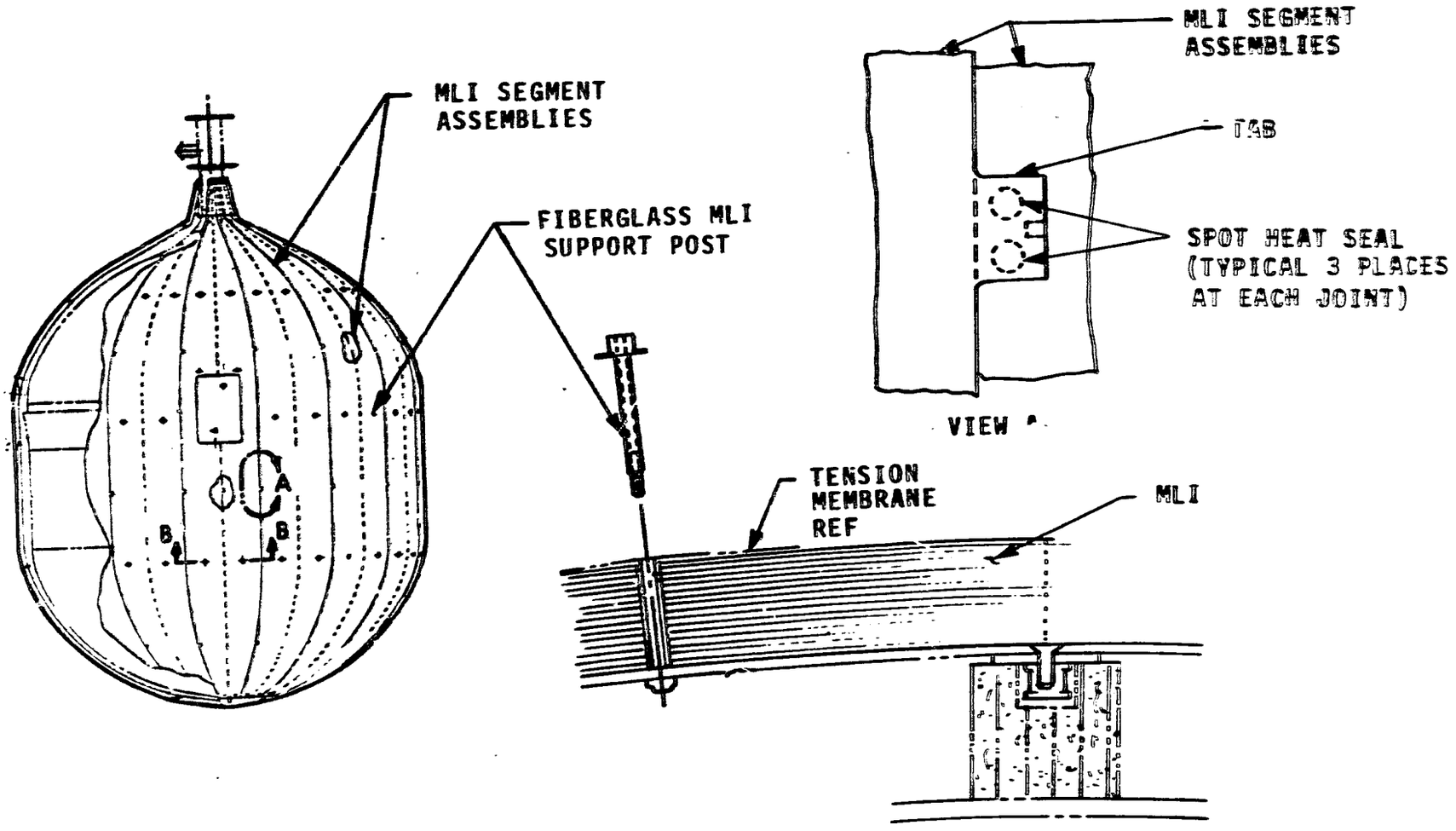


Figure 6.1.10.1-1. MLI Installation Natural Lay Concept

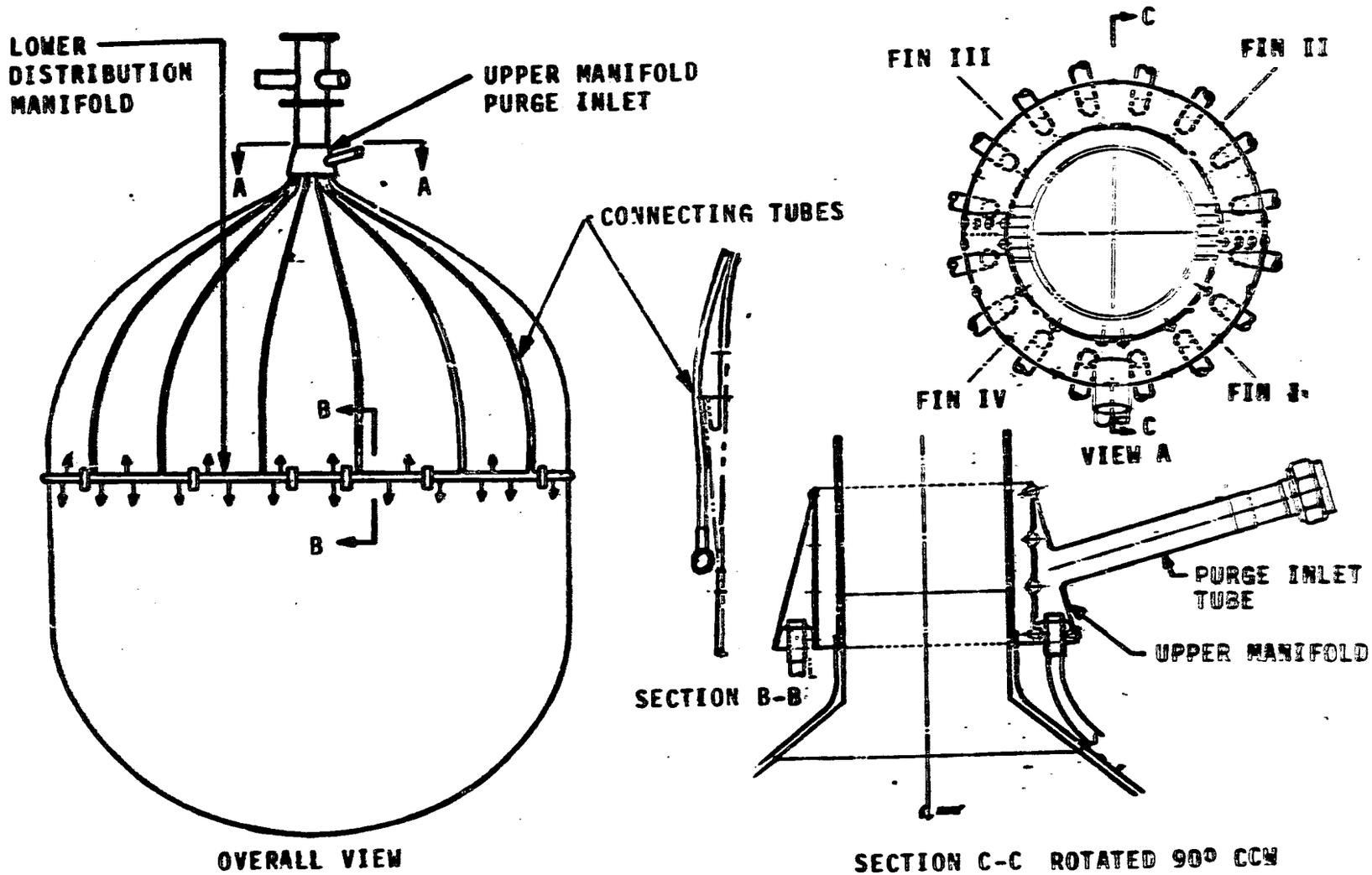


Figure 6.1.10.1-2. Inner Purge System

Space Division
North American Rockwell

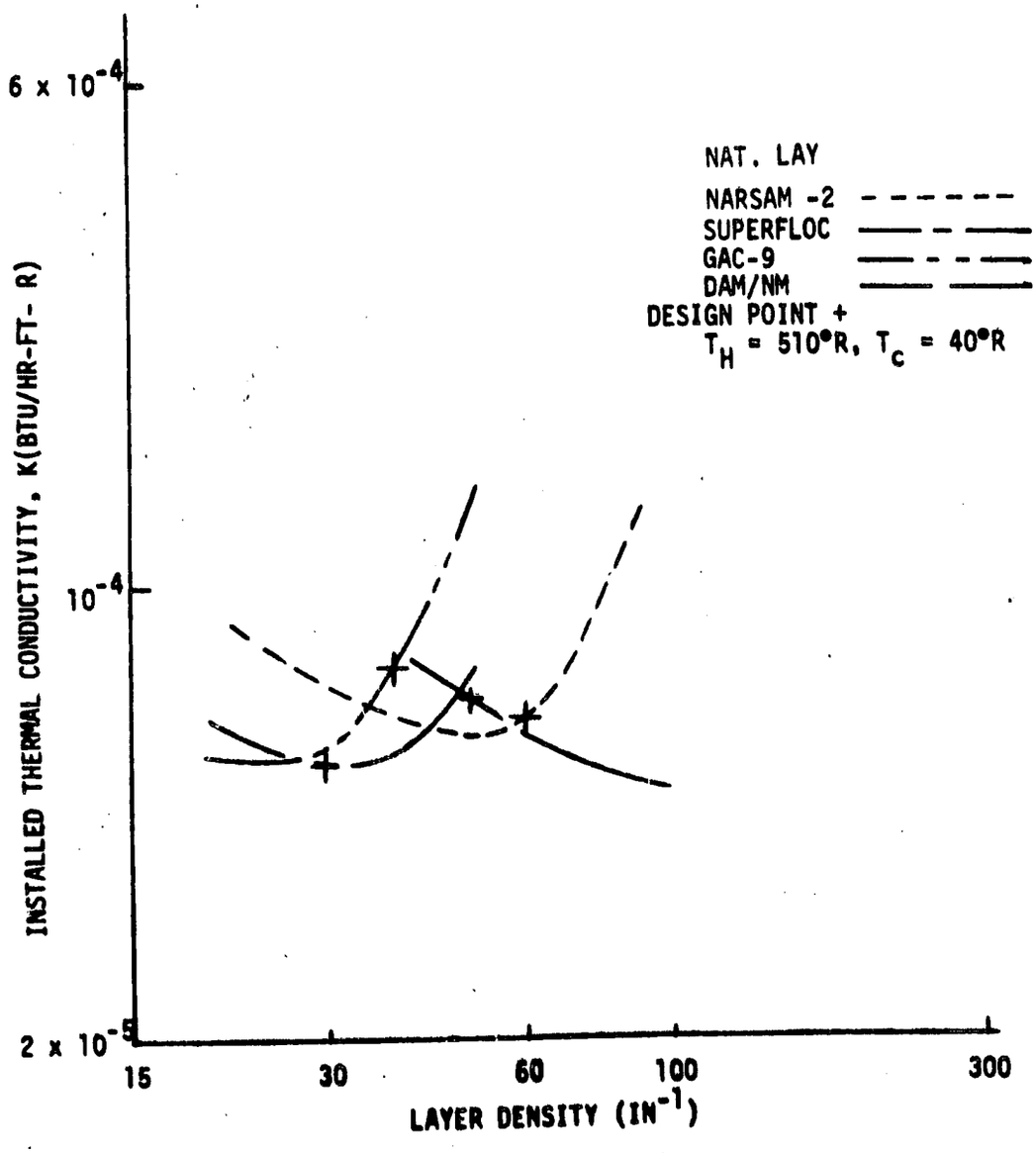


Figure 6.1.10.2-1. Installed Thermal Conductivity

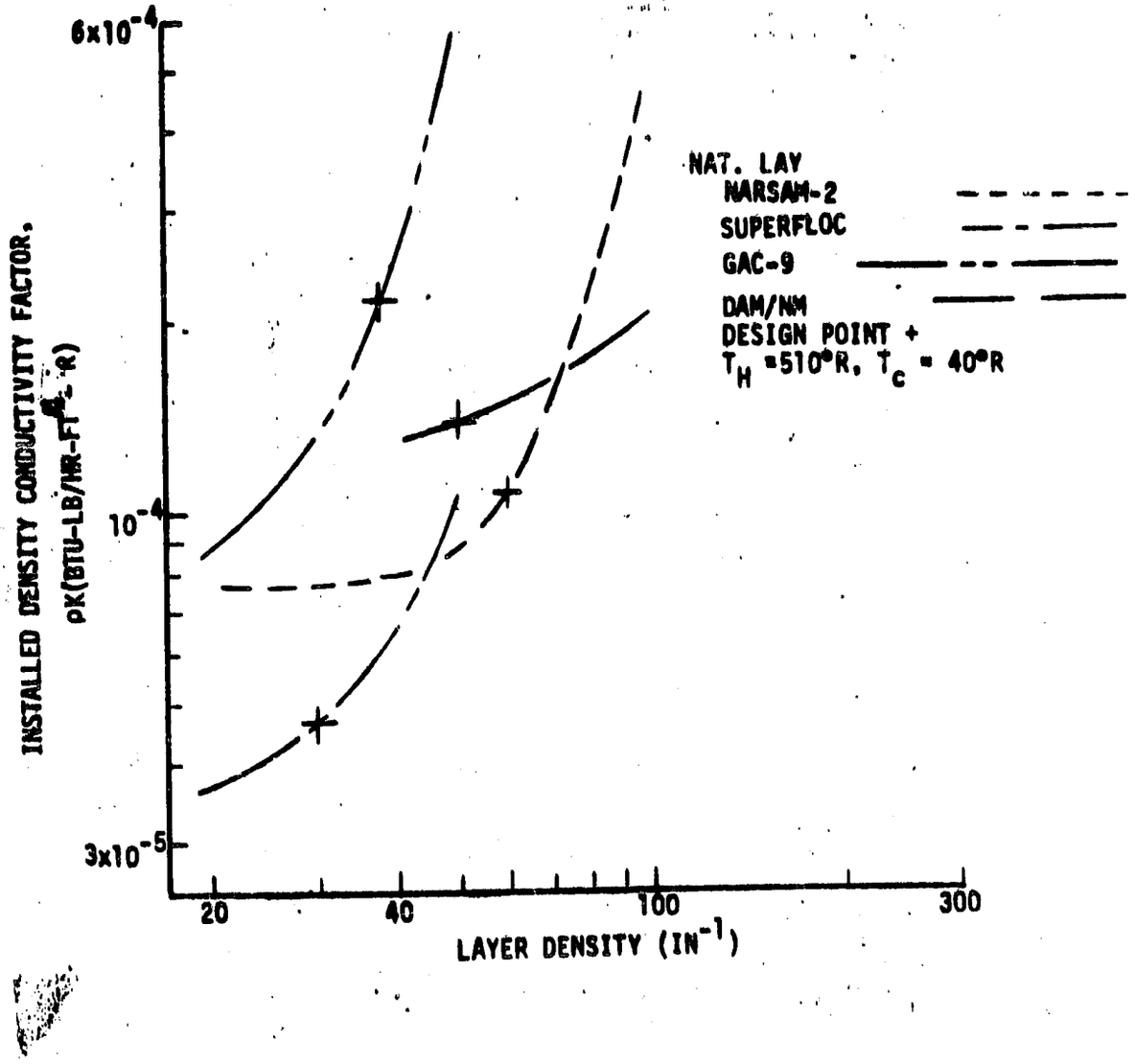


Figure 6.1.10.2-2. Installed Density/Thermal Conductivity Product

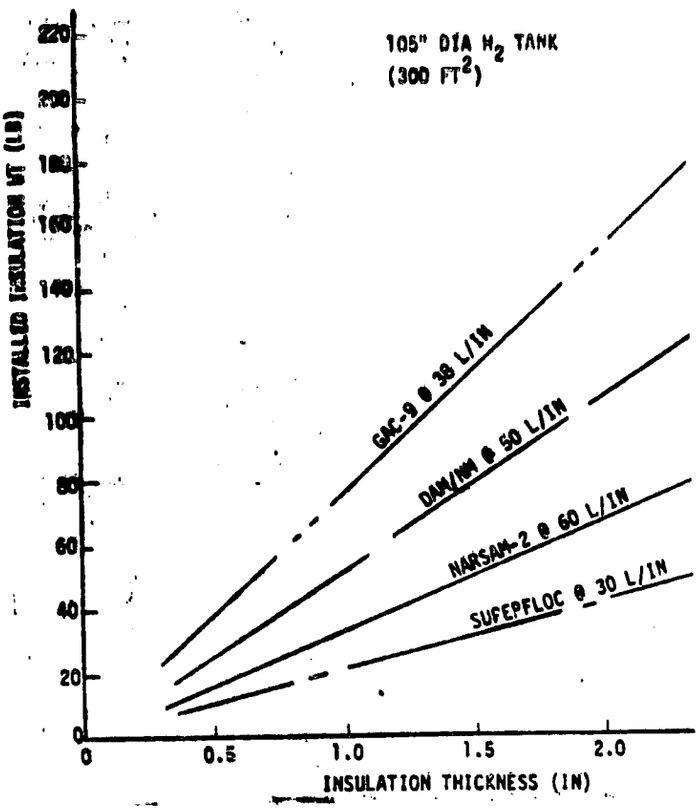


Figure 6.1.10.2-3. 105-Inch Tank Insulation Weight

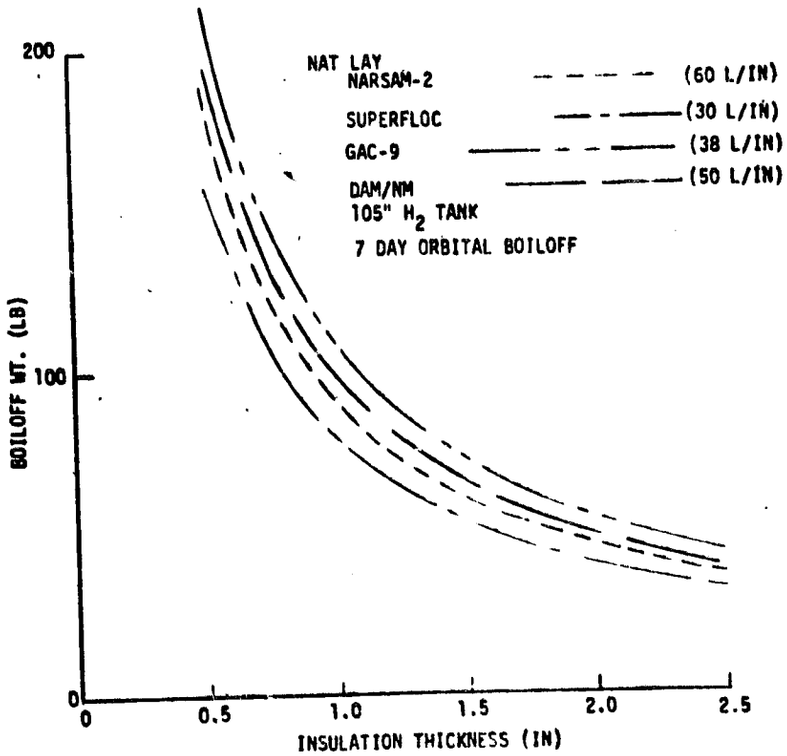


Figure 6.1.10.2-4. 105-Inch Tank Orbital Boiloff

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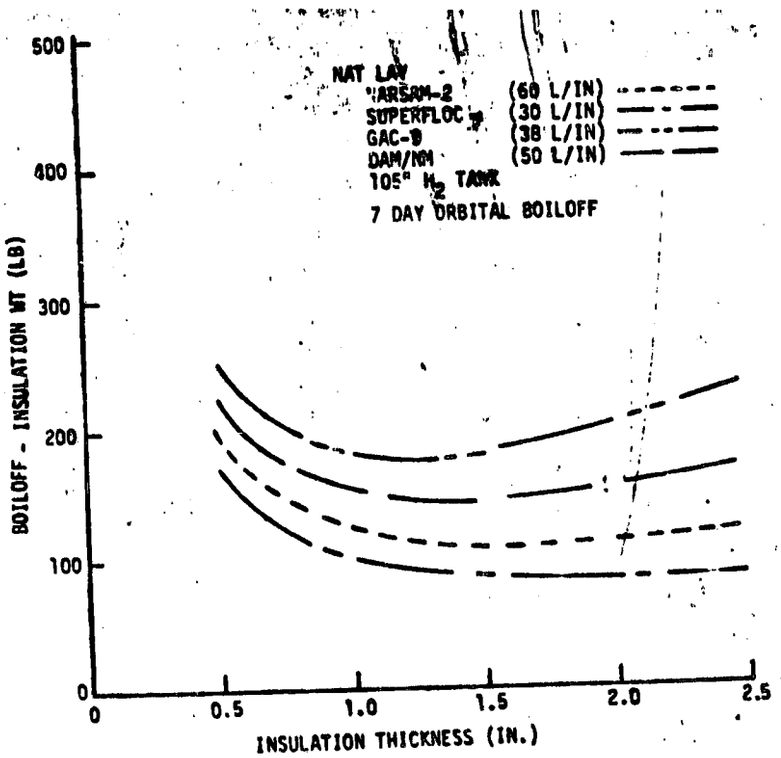


'Figure 6.1.10.2-5. 105-Inch Tank Orbital Boiloff and Insulation Weight

Table 6.1.10.2-1. MLI Design Problems and Solutions

Problem	Solution
1. Low evacuation rate during orbit insertion	Provide perforations in MLI of sufficient size and number to permit evacuation to required pressure in required time; verify by test
2. Embossment pattern of insufficient depth	Determine optimum layer density by test; establish program with material supplier to change variables such as alizing speed, temperature, and pressure roll tension; produce sufficient depth to allow for material memory
3. Embossment of Kapton not permanent	Polyimide material must be processed differently than Mylar because of memory; insufficient development conducted to date
4. MLI emittance higher than anticipated	Work with material supplied to provide better aluminized surface after embossing; evaluate production sequence to determine effect on emittance of final product; emittance measurement technique for embossed material is state of art
5. Fragile material tears when placed over plastic studs	Use adhesive-backed reinforcement washers around hole

e. Design Verification Tests: No tests have been conducted on the simplified natural layup concept. Tests were conducted on the preceding forced density control configuration, however, with the following results:

1. Flat Plate Calorimeter: Effective thermal conductivity of 1.74×10^{-5} Btu/hr-ft-R was demonstrated for $T_h = 510$ R and $T_c = 40$ R.

2. 3-Foot by 4-Foot Calorimeter: Installed effective thermal conductivity of 3.19×10^{-5} Btu/hr-ft-R for the same ΔT condition was demonstrated.

6.1.10.3 Thermal Performance

The thermal performance characteristics of this insulation system are given for a tank containing LH_2 which is exposed to simulated ground-hold, launch, orbit, and reentry environments. A detailed description of the design configuration, predicted performance, analysis methods, and subscale test evaluation are presented in the final report for Cryo Storage Thermal

Improvement Study (SD 71-263). The predicted thermal performance characteristics are summarized below.

A NASA/MSFC 105-inch diameter LH_2 tank has been insulated with NARSAM-2 for testing at MSFC. The total insulation system includes internal and external preconditioning systems for MLI drying prior to use, inner and outer membranes to support MLI, and an external purge bag for environmental isolation. NARSAM-2 MLI is singly aluminized Mylar with a random embossment pattern. The configuration as installed on the 105-inch diameter tank is referred to as a "natural-layup" concept. This concept takes advantage of the embossment height and intrinsic material stiffness to maintain layer separation, and negates the need for pins or separators to maintain layer density control. The physical characteristics of the "installed" system are presented in Table 6.1.10.3-1.

Table 6.1.10.3-1. NARSAM-2 MLI System Physical Characteristics

Characteristic	Value
NARSAM-2	
Mylar substrate thickness	0.25 mil
Aluminum thickness	>250 Å
Layer density (N)	60 layers/in.
Aluminum surface emittance (ϵ_{al}) after embossment and perforation as installed on tank	<0.045; inner 1/3 layers <0.065; outer 2/3 layers
Percent area perforations	2
Density of MLI only (ρ_{MPI})	1.38 lb/ft^3
Internal pressure	<3 x 10^{-5} Torr
Natural Layup (on 105-inch tank)	
Number of layers on tank	90
Number of layers per module	5
Number of modules	18
Number of segments around tank periphery	16
Thickness of MLI	1.5 in.
Number of 0.214-inch-diameter MLI supports (12-MIL wall)	156
Density of MLI including outer tension membrane weight	1.75 lb/ft^3

Subscale tests were performed to ascertain the thermal performance of NARSAM-2 MLI. A value of $K_{MLI} = 3.38 \times 10^{-5}$ Btu/hr-ft-°F was measured. Based on the subscale testing, correlation, and analysis, the predicted orbital thermal performance of the MLI as installed on the 105-inch tank is presented in Table 6.1.10.3-2. The inner 30 layers ("in-specification" material) have an emittance (ϵ_{AL}) of <0.045 and a corresponding thermal conductivity (K_{MLI}) of 3.38×10^{-5} Btu/hr-ft-°F. The outer 60 layers ("out-of-specification" material) have $\epsilon_{AL} < 0.065$ and $K_{MLI} = 4.36 \times 10^{-5}$ Btu/hr-ft-°F. The composite has an effective $K_{MLI} = 3.91 \times 10^{-5}$ Btu/hr-ft-°F. The predicted orbital heat flux into LH_2 is approximately 0.2 Btu/hr-ft^2.

Table 6.1.10.3-2. Predicted Thermal Performance of NARSAM-2 on 105-Inch Diameter Tank

Area	Value
Orbital Performance	
MLI (including perforations)	3.91×10^{-5} Btu/hr-ft °F
Support Posts	0.80
Segment Joints	0.30
K_{MLI}	5.01×10^{-5} Btu/hr-ft °F
Thermocouple Leads	0.05
Pressure Probe	0.15
Overall Thermal Conductivity for 105-inch Tank Installation	5.21×10^{-5} Btu/hr-ft °F
Orbital Heat Flux	0.202 Btu/hr-ft^2
Ground-Hold Performance	
MLI (Helium Gas)	0.060 Btu/hr-ft °F
Heat Flux	140 Btu/hr-ft^2

During ground-hold, the effective K_{MLI} is the thermal conductivity of the residual gas between MLI layers. Since a helium-purge is recommended, $K_{MLI} = 0.060$ Btu/hr-ft °F. The overall heat transfer rate for 500 FΔT is approximately 140 Btu/hr-ft^2. A flow-through purge does not alter the ground-hold thermal performance as long as hot gas does not blow directly on the tank wall. If hot gas is admitted next to the cold wall during ground hold, the overall heat flux to LH_2 is increased to approximately 1000 Btu/hr-ft^2.

The use of Mylar or Kapton as the substrate for the aluminum does not alter the effective K_{MLI} nor the overall heat flux to LH_2 through NARSAM-2 MLI. However, Mylar melts at approximately 200 F, which could present problems during boost or reentry of a space vehicle into a planetary atmosphere.

6.1.10.4 Structural Performance

Critical structural loading on this insulation system results from differential pressure across the MLI and from "g" levels due to launch vehicle acceleration.

Significant factors affecting the strength of this insulation system are:

a. This insulation system utilizes organic materials which exhibit a visco-elastic behavior. The structural behavior of organic materials is discussed in Section 8.0.

b. Design of the MLI to support post attachments to prevent local bearing or shear failure of the MLI at the attachments.

6.1.10.5 Material and Processes

a. Material: The film is an embossed aluminized polyester (MB0135-034).

b. Processes: The processes for the fabrication of MLI are given in V7-953570. This document covers all phases of insulating a 105-inch diameter tank. The document only covers the basic M&P requirements of handling and environment. Any further production of this configuration would require a program for the development of the processes and the writing of a specification.

6.1.10.6 Manufacturing

a. Description: MLI-flow-through purge on the 105-inch tank consisted of a lattice-work of fiberglass strips surrounding the tank assembly and attached to the tank wall by means of a pattern of honeycomb/foam hardspots. An inner purge manifold of welded tubing was installed near the tank wall surface to distribute helium gas. The exterior of the support frame assembly is covered by an inner membrane fabricated of aluminim screen wire; this provides a continuous porous surface to prevent the aluminized Mylar insulation from sagging through the openings in the lattice framework. The lattice framework provides attach points for fiberglass posts which attach and support the insulation.

   The MLI is a 1.5-inch-thick blanket of aluminized Mylar sheets of 0.25-mil thickness. The individual sheets are made into five-layer module segments. Sixteen module segments are required for one full tank circumference, and 18 layers of module segments are required to achieve the required 1.5-inch thickness of total insulation.

After the insulation is installed, an outer membrane made of plastic mesh is installed over the insulation.

The insulation was tested and flow rates of air were recorded.

The manufacturing flow and sequence diagram (Figure 6.1.10.6-1) presents the build plan.

b. Tooling and Equipment: Tooling consisted of an assembly fixture for the purge cage assembly, hydro-form dies for sheet metal components, slush molds and plastic layup dies for glass cloth laminate, and Mylar templates for fabrication of MLI module segments. Hardspot and sweep templates were provided for locations and contours, respectively.

Equipment consists of a spray foam station, air conditioning unit, bridge crane, lighting and electrical outlets, work tables, adjustable work platforms, holding fixture to hoist the 105-inch tank, and a transportation dolly.

6.1.10.7 Quality Assurance

The MLI described was developed on a study contract and did not reach true production status. Extensive quality control procedures were developed, however, in the course of the study effort. Emphasis was placed on control of the aluminized Mylar raw material because of the requirement that the material be produced and maintained with minimal exposure to atmospheric moisture.

a. Raw Material Control (MB0135-034)

1. Supplier Surveillance: Formal source inspection was not invoked at the supplier of the MLI raw material. However, a Quality Engineering representative was present at the supplier's facility during the vacuum drying and packaging operations specified in MB0135-034. It was verified that each roll of MLI material was subjected to the required vacuum drying operation and properly packaged and desiccated, within 30 minutes, for shipment.

2. Supplier Material Certification: The supplier was required to submit a Certificate of Conformance with each shipment of raw material relative to:

Raw material composition
Mylar thickness
Stack height
Emissivity
Coating adhesion
Embossment pattern
Perforation pattern
Aluminized coating thickness

The requirements and test procedures were established in MB0135-034.

3. Receiving Inspection: Formal receiving inspection was waived for the MLI raw material. The material was procured as a special buy. Essentially, this procedure allowed the material to be shipped directly to the using department with no receiving inspection. This procurement policy was established because of the complex packaging techniques employed in raw material transit coupled with the environmental controls established for the MLI. Implementation of this procedure provided for the material to be unpackaged in a controlled (temperature and relative humidity) and monitored environment where samples were obtained for laboratory acceptance testing.

4. Material Validation and Storage: The material was stored in an area with controlled temperature and humidity in conformance with the requirements of MB0135-034. The environmental conditions were monitored by a hygrothermograph equipped with a seven-day readout chart. Upon completion of each seven-day interval, Inspection dated and stamped each chart, noting the lot numbers stored at that time.

   Immediately upon receipt of the material, each carton was opened in the presence of Inspection. The integrity of the sealed bags was verified and the MS20003 humidity indicator card was checked. Approximately five yards of each roll of material was removed and transferred to the laboratory for validation testing. Tests included:

   Overall quality and condition
   Stack height
   Coating adhesion
   Embossment pattern
   Perforation pattern
   Roll width

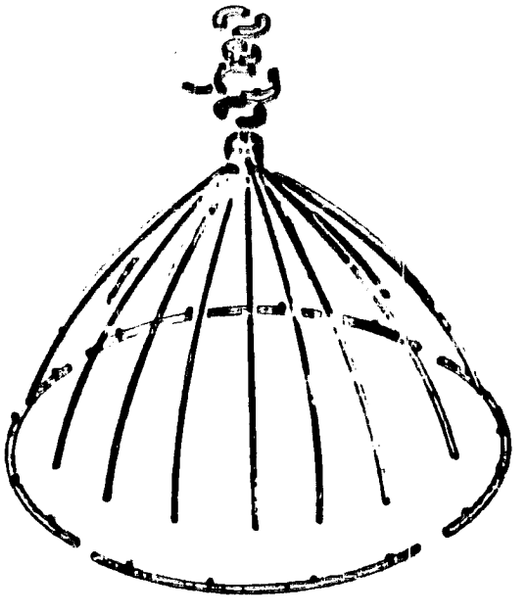
b. Subassembly Process Control:

1. Environmental Control: The 105-inch tank work station was environmentally controlled during the time the MLI was exposed to the work station environment. Maximum relative humidity allowed was established as 60 percent. There was no maximum or minimum established for temperature; however, the temperature was continuously monitored.

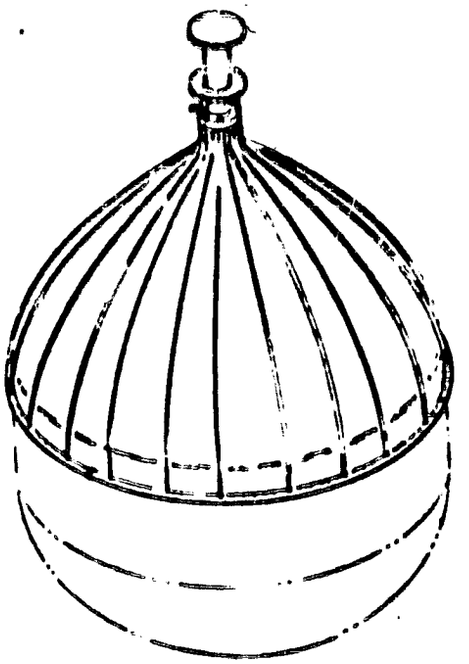
2. Pre-Process Visual: Two cutting tables were installed in the work station sufficiently large enough to support the largest MLI details. The rolls of MLI material were mounted at the end of each table. As the material was rolled onto the cutting table a 100-percent visual inspection was conducted to verify the material to be free from irregularities associated with the perforation pattern, embossment, tears, taped seams, wrinkles, and any other obvious visual discrepancies.

3. Verification of Metalized Surface: Verification of the metalized surface was made by determining the conductive surface of the aluminized Mylar film. This spot check was performed initially as the film was unrolled onto the cutting cable. A final check was performed on each

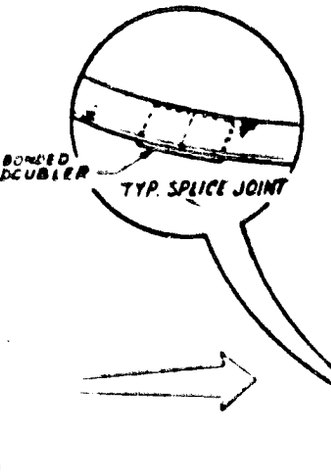
FOLDOUT FRAME

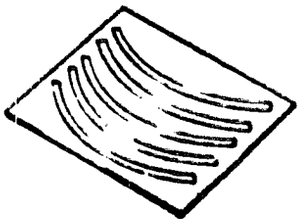


- INNER PURGE MANIFOLD DETAIL FABRICATION
- DETAIL FABRICATION TO BE PER TEMPLATES & LAYOUT
- FAB WELDED SUB-ASSEMBLIES

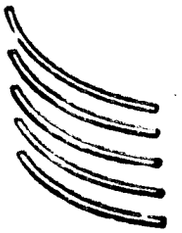


- ASSEMBLE INNER PURGE MANIFOLD ON TANK
- LOCATE MANIFOLD SUPPORT HARDSPOTS





- LAYOUT FIBERGLASS LATTICE STRIPS PER TEMPLATES



- TRIM FIBERGLASS LATTICE STRIPS

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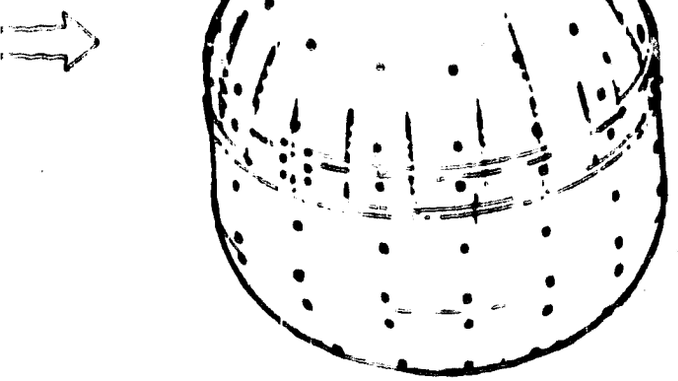
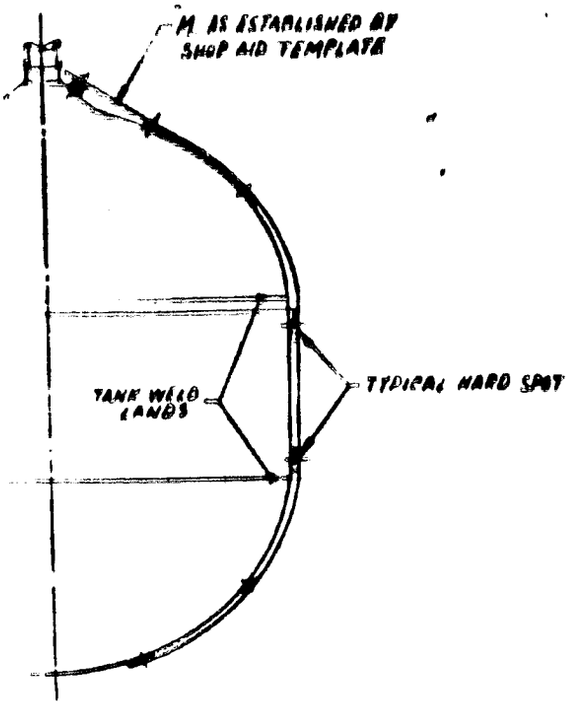
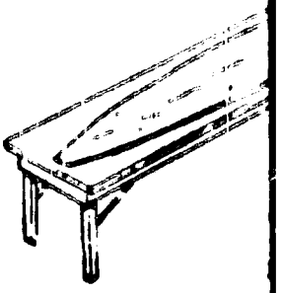


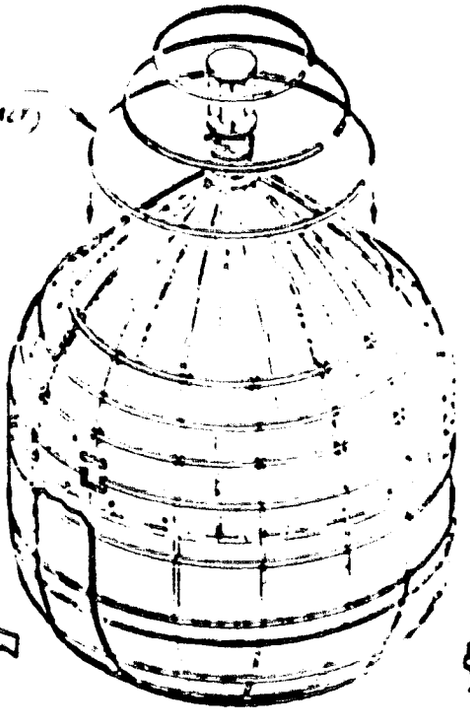
• LOCATE & BOND ALIGNMENT HARD SPOTS (HARD SPOT LOCATIONS ESTABLISHED PER LAYOUT)

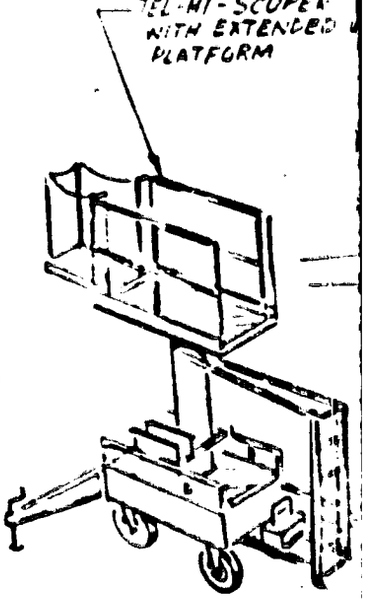


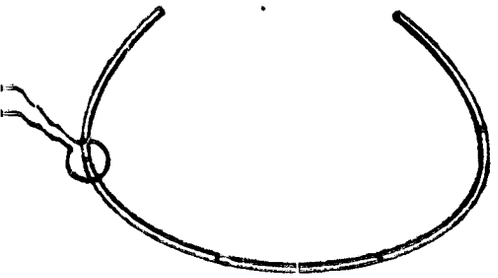
• HARD SPOT M ELEVATION



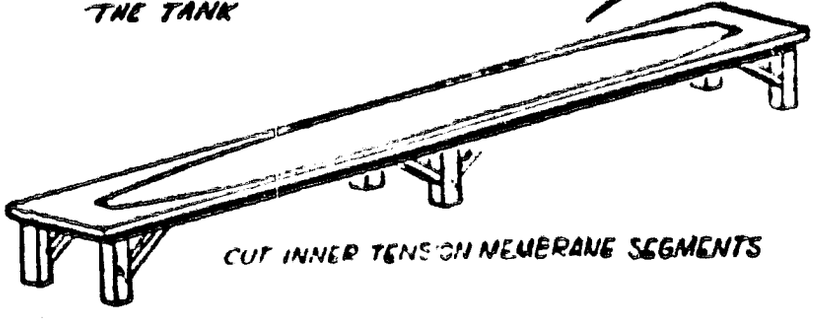
FIBERGLASS LATTICE STRIPS (HAND FIT & LAYUP TO TANK CONTOUR)







• BOND STRIPS TO OBTAIN REQUIRED LENGTH
• BONDING MAY BE DONE ON OR OFF THE TANK

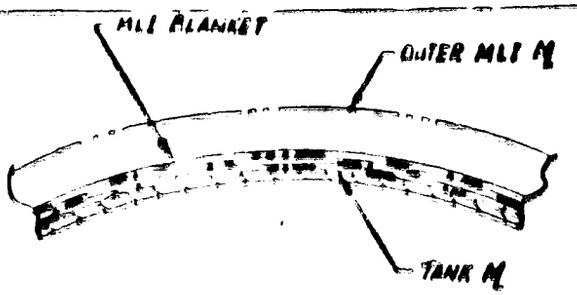


CUT INNER TENSION MEMBRANE SEGMENTS

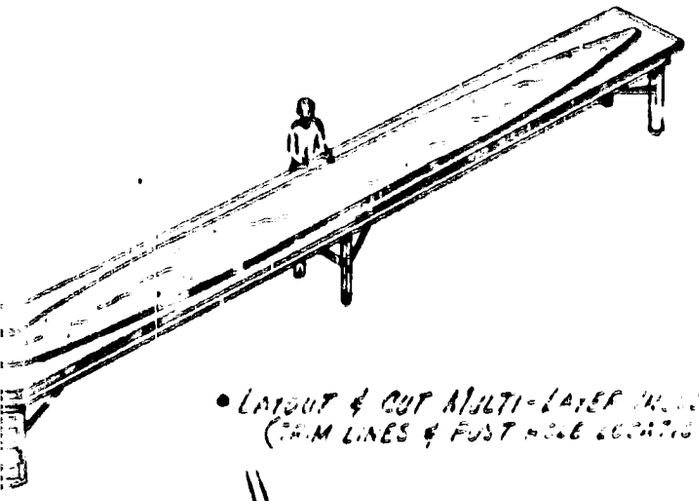
• INSTALL INNER PURGE MANIFOLD & FIT & LAYUP FIBERGLASS LATTICE STRIPS
• LOCATE POSTS FOR MLI

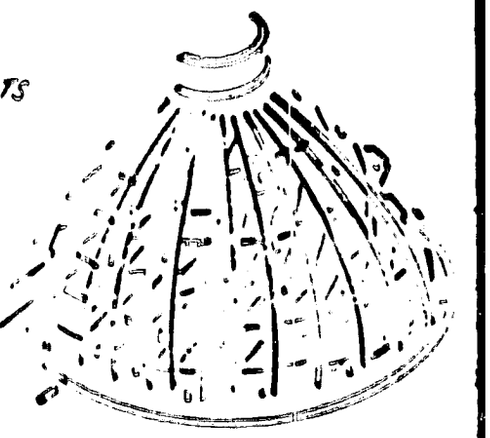
• INSTALL INNER TENSION MEMBRANE SEGMENTS

FOLDOUT FRAME 3



SECTION E-E
OVER LAPING OF MLI BLANKETS DURING INSTALLATION

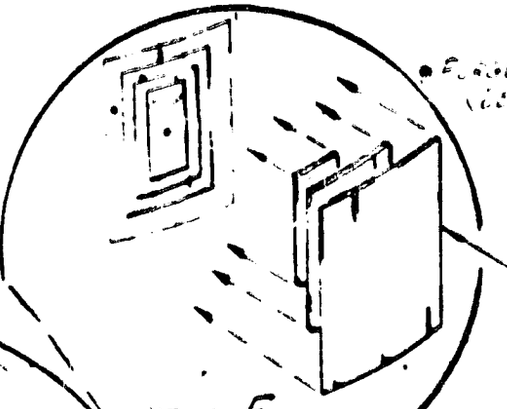




• LAYOUT & CUT MULTI-LAYER INSULATION (MLI) BLANKETS
(TRIM LINES & PUNCH HOLE LOCATIONS ESTABLISHED PER TEMP & LAYOUT)

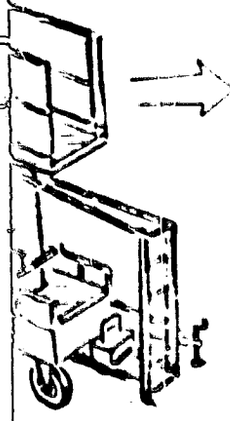
• BLANKET CHAMBER DETAIL FABRICATION
(DETAILS ROLL FORMED PER TEMPLATES &

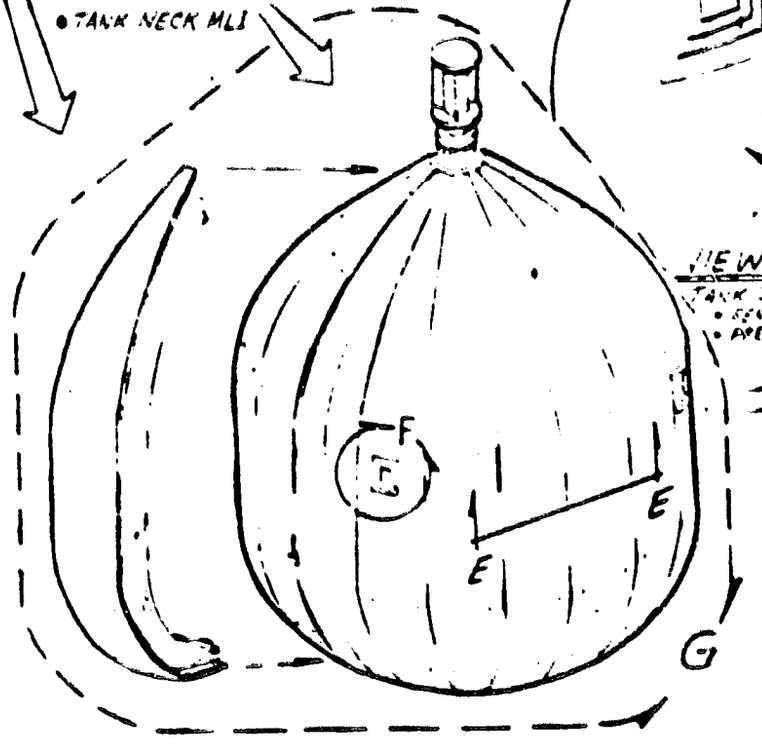
• TANK NECK MLI



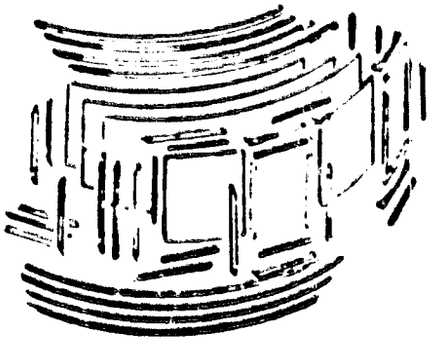
VIEW F
TANK SUPPORT ASM CLOSEOUT
• REMOVE SUPPORT FITTING
• REFIT MLI BLANKETS

MI-SCOPER
W EXTENDED WORK
TFORM





• INSTALL MLI MODULES

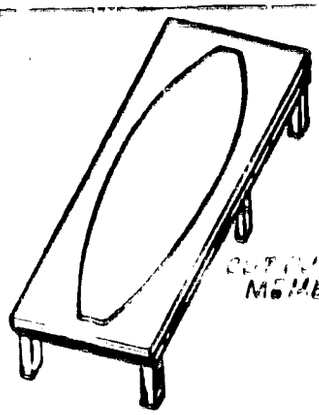


• RING ASSEMELY DETAIL FABRICATION
(DETAILS ROLL FORMED PER TEMPLATE)

• AFT MLI CLOSEOUT BLANKETS

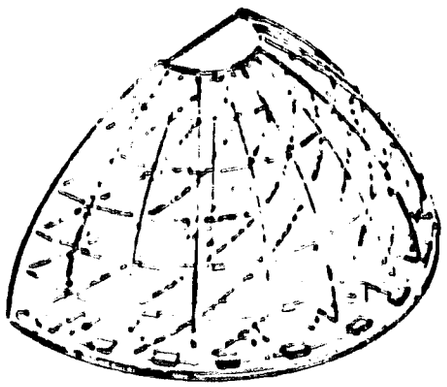
VE

FOLDOUT FRAME 4



CUT OUT OUTER TENSION MEMBRANE SEGMENTS

DETAIL FABRICATION
(TEMPLATES & FORM BLOCK)

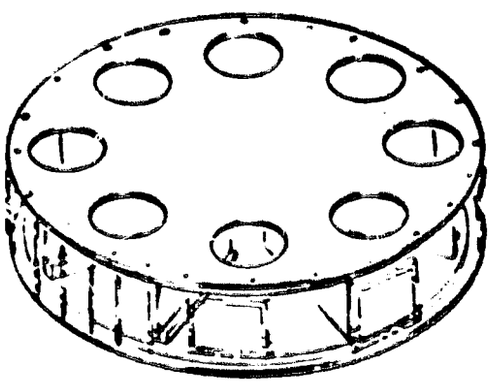


• PURGE CHAMBER SUB-ASSEMBLY

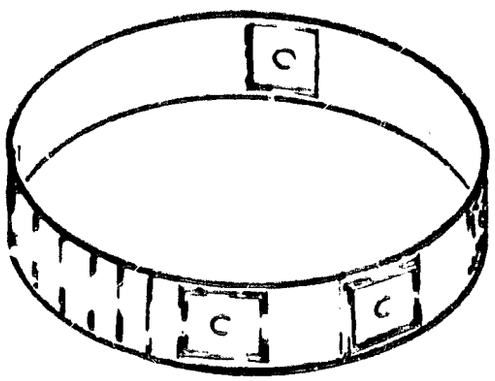
TENSION MEMBRANE
ASSEMBLY JIG

SETS

FABRICATION
& TEMPLATE)

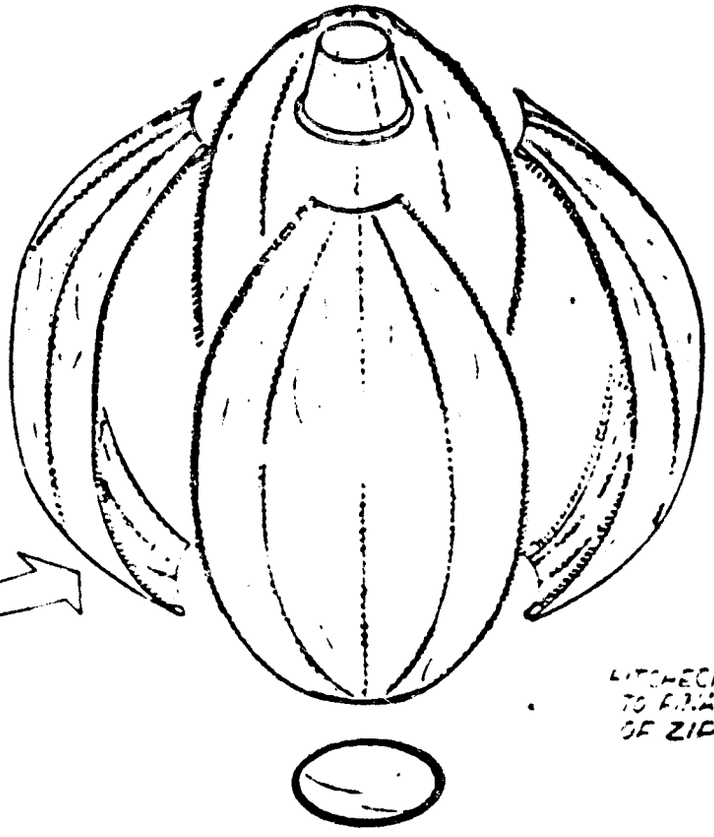


• ASSEMBLE RING ASSEMBLY

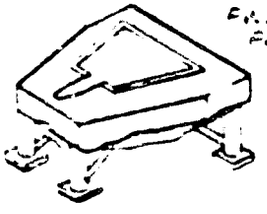


• CENTER RING ASSEMBLY
(PURGE CHAMBER)

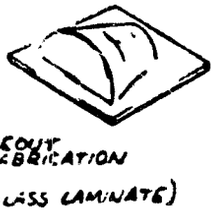
FOLDOUT FRAME 5



LEAK CHECK ON TANK PRIOR TO FINAL INSTALLATION OF ZIPPERS



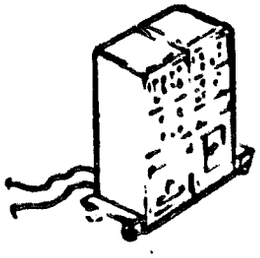
F.R.P. CLOSEOUT PLASTER MOCKUP



PURGE CHAMBER FLOW TEST PLUG

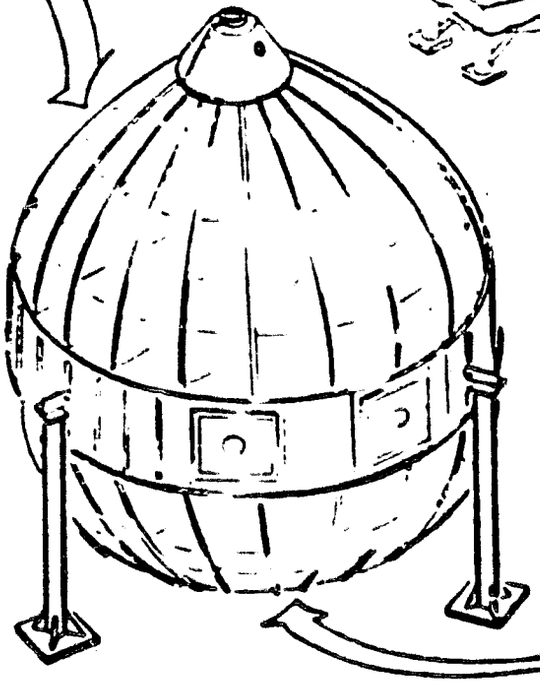
PURGE CHAMBER RING ASSEMBLY

• F.R.P. CLOSEOUT TOOL FABRICATION (FIBERGLASS LAMINATE)



PURGE CHAMBER FLOW T

• PURGE CHAMBER-PURGE FLOW TEST



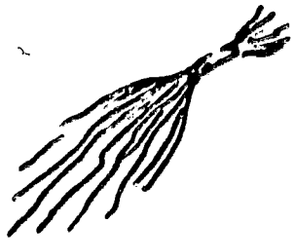
ASSEMBLE & LEAK CHECK PURGE BAG ASSY

• AFT CLOSEOUT ASSEMBLY

AFT CLOSEOUT DETAIL ASSEMBLY

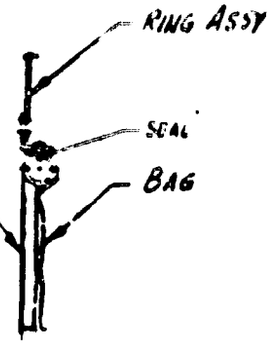
PURGE GAS OU

AFT C



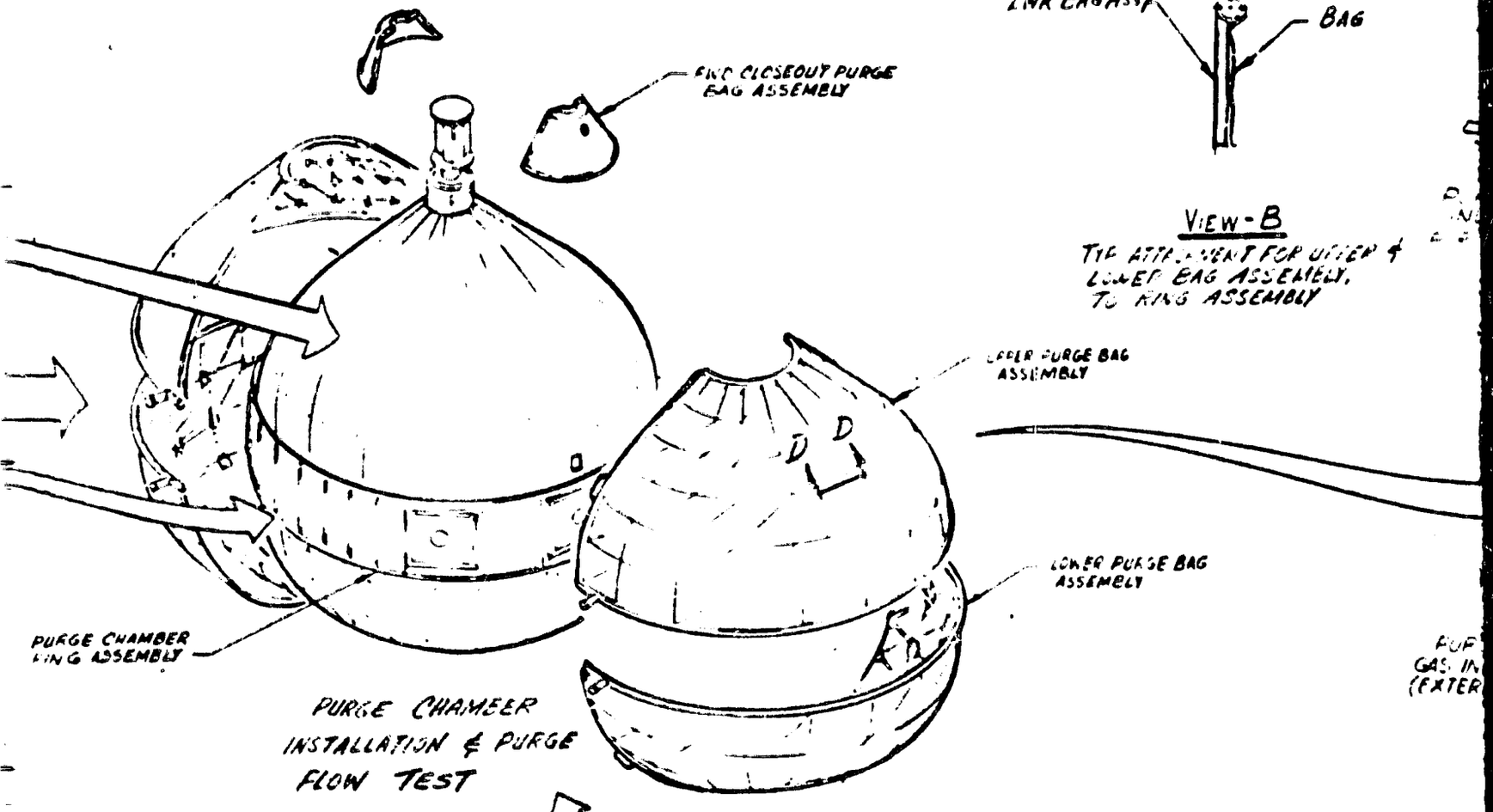
• INSTRUMENTATION WIRE HARNESS

• TUBE ASSY (PURGE CHAMBER)



VIEW-B

TYP ATTACHMENT FOR UPPER & LOWER BAG ASSEMBLY, TO RING ASSEMBLY



PURGE CHAMBER INSTALLATION & PURGE FLOW TEST

• AFT CLOSEOUT ASSEMBLY

MBER FLOW TEST PLUG

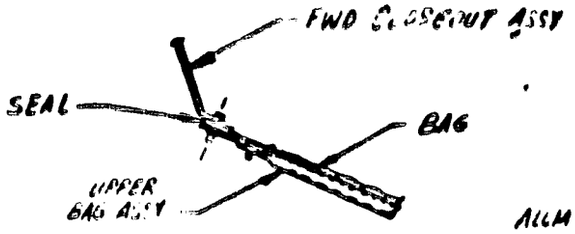
LOW TEST

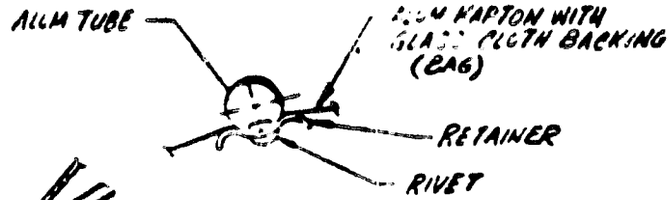
RGE GAS OUTLET FITTING

AFT CLOSEOUT DETAIL FABRICATION (FIBERGLASS LAMINATE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

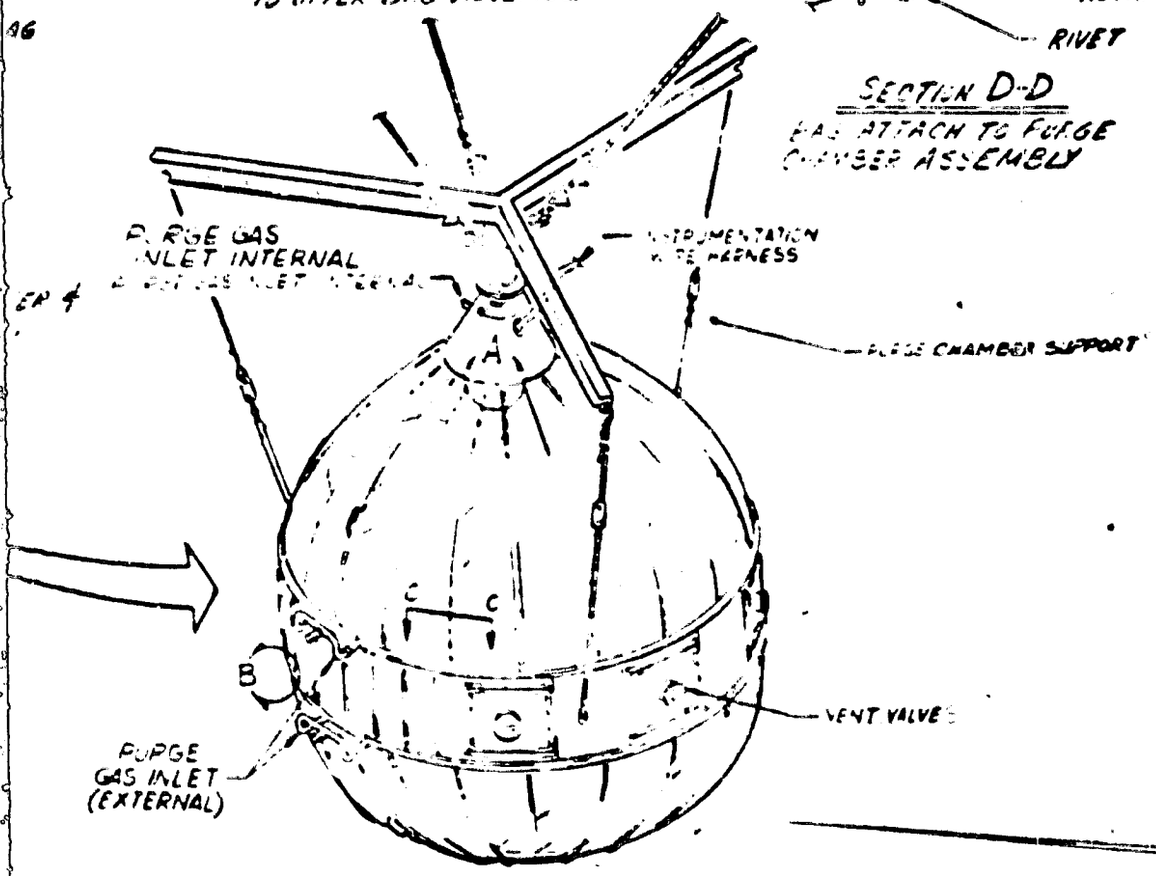
FOLDOUT FRAME 7



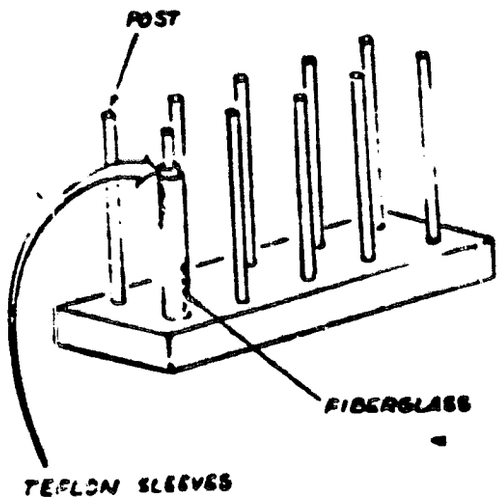


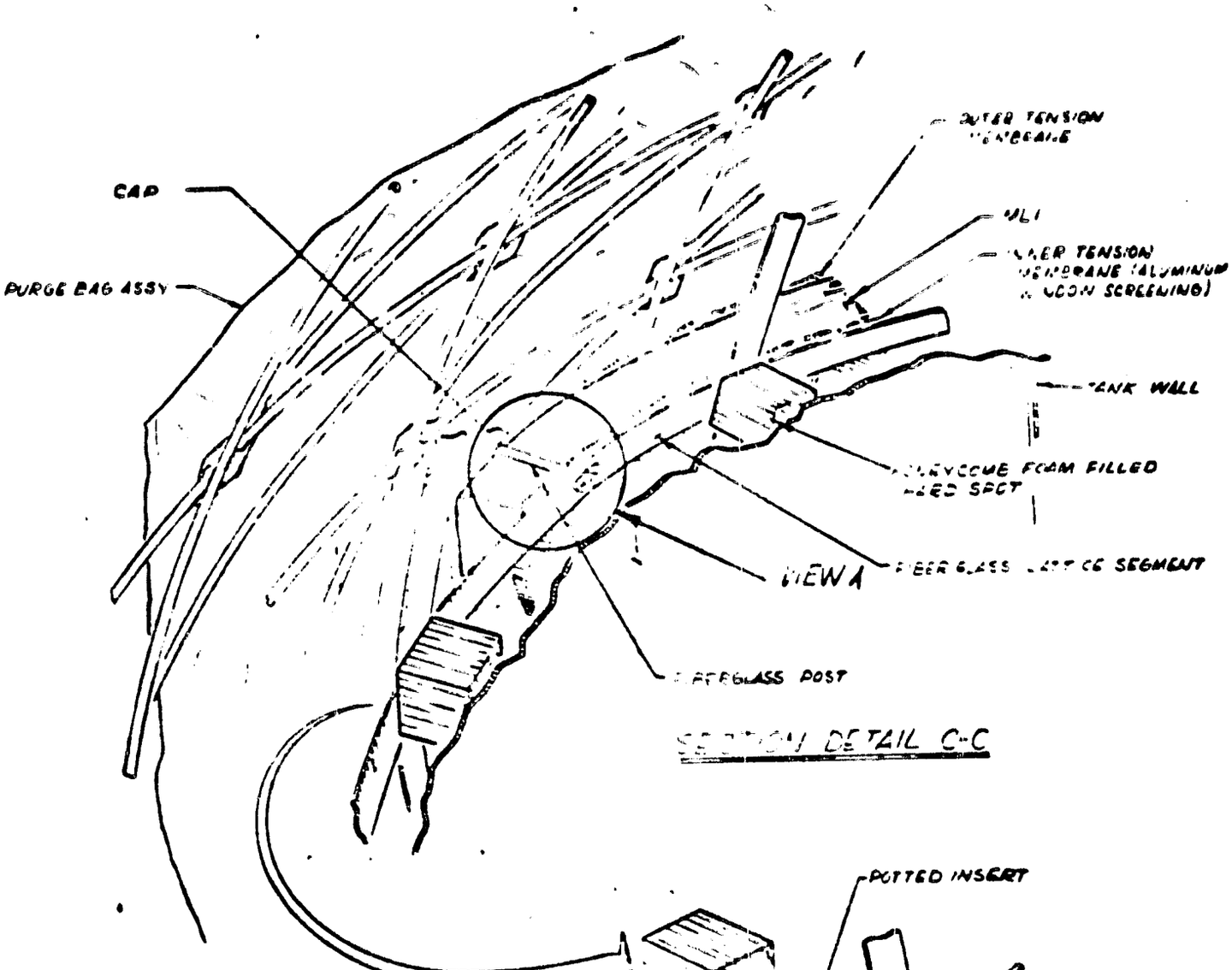
VIEW A
FWD CLOSEOUT ATTACH TO UPPER BAG ASSEMBLY

SECTION D-D
BAG ATTACH TO PURGE CHAMBER ASSEMBLY

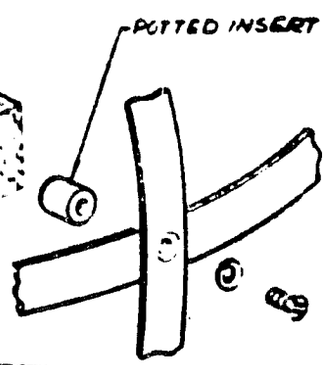


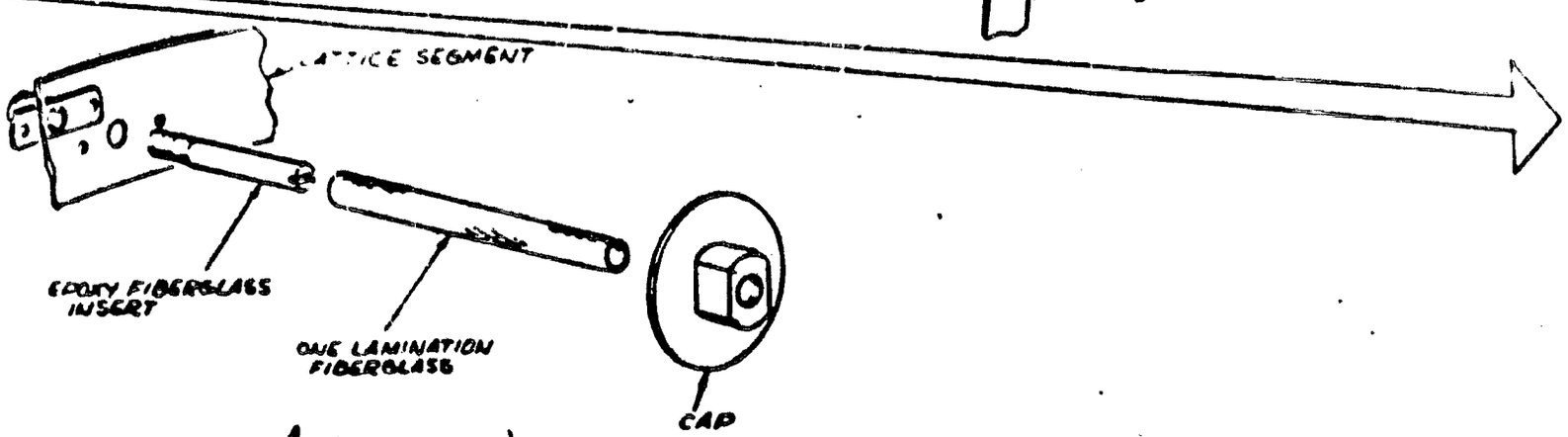
• COMPLETED TANK ASSY WITH PURGE CHAMBERS ASSEMBLED





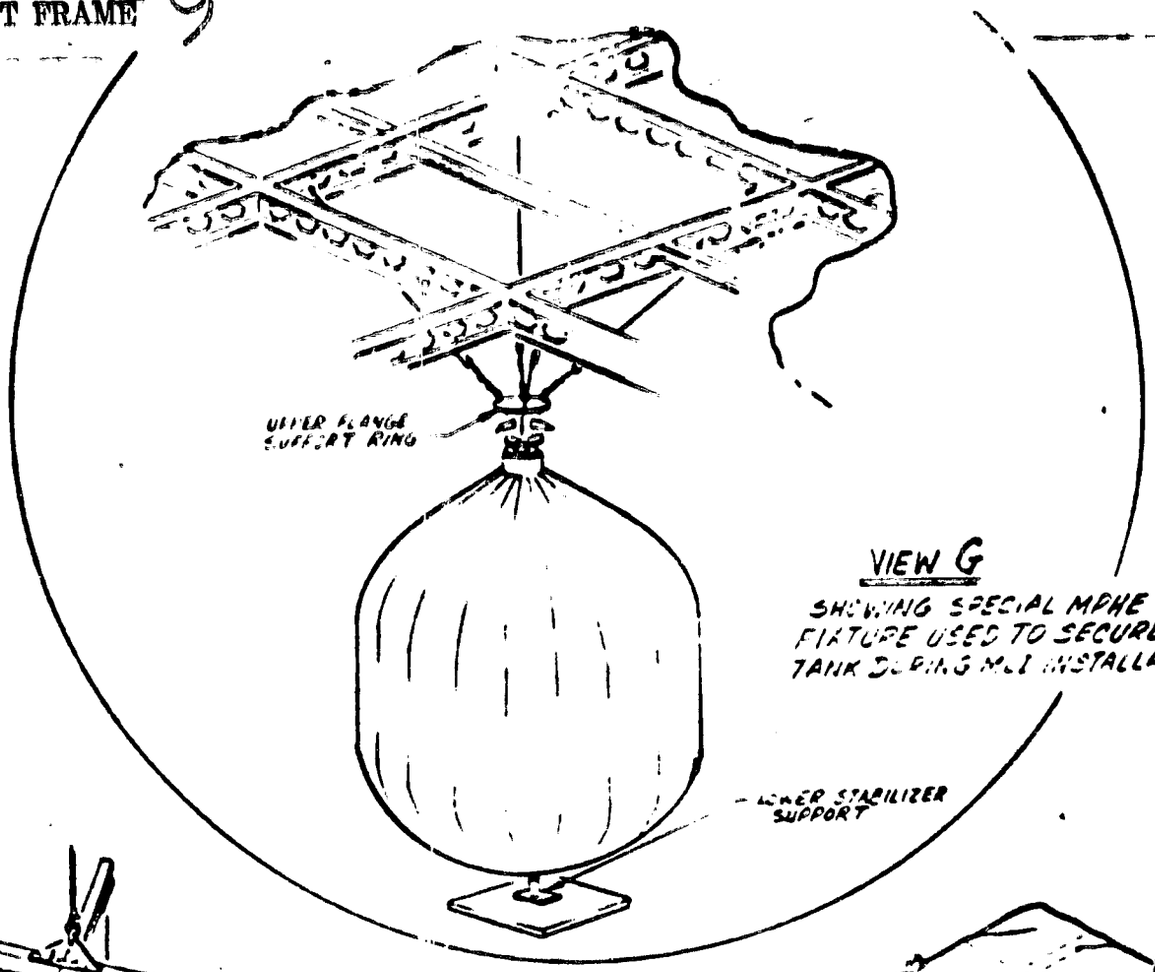
SECTION DETAIL C-C





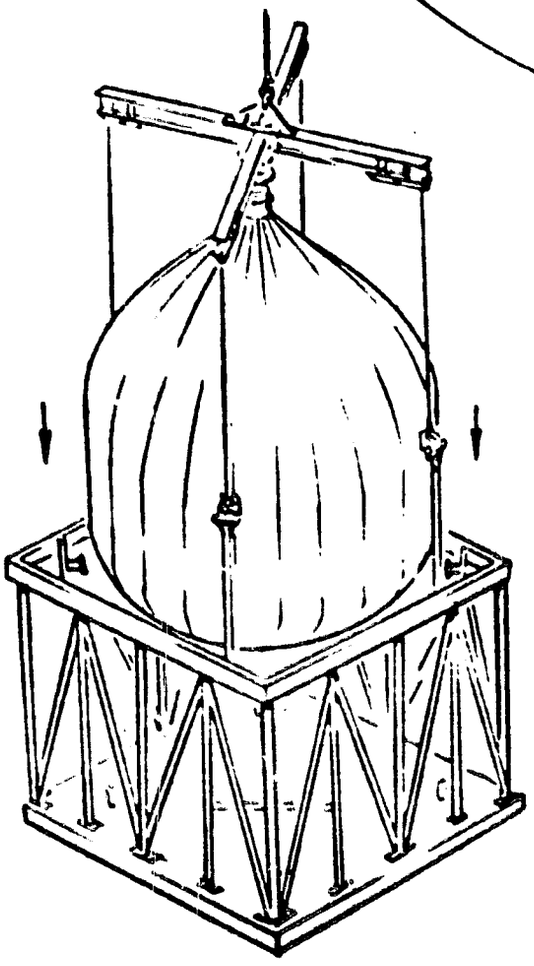
VIEW A (ROTATED 180°)

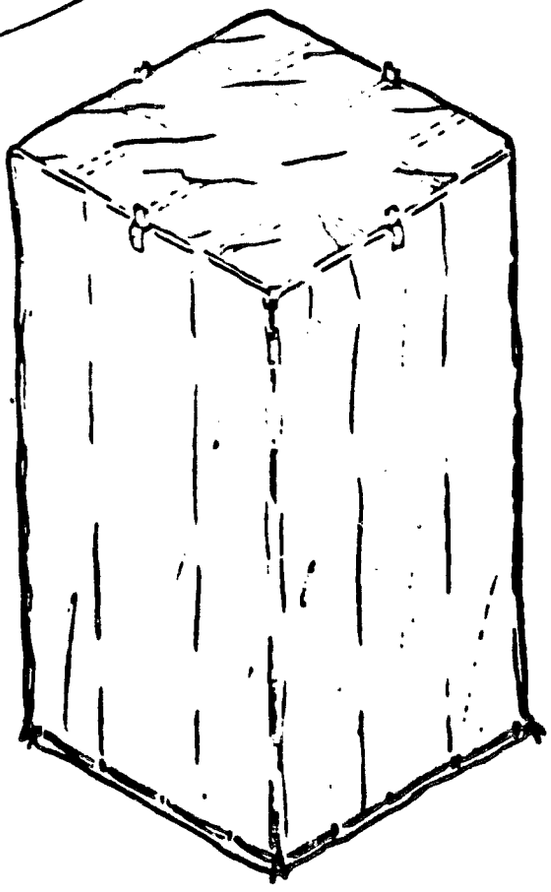
FOLDOUT FRAME 9



VIEW G

SHOWING SPECIAL MPHE FIXTURE USED TO SECURE TANK DURING MLI INSTALLATION





- PLACE COMPLETED TANK IN LOWER SECTION OF SHIPPING CONTAINER
- ASSEMBLE UPPER SECTION OF CONTAINER & SECURE TANK

- INSTALL PLASTIC COVER OVER SHIPPING CONTAINER, FOR SHIPPING

Figure 6.1.10.6-1. Multilayer Insulation Flow Thru Purge

layer of film upon completion of the five-layer MLI blanket module immediately prior to installation on the test tank.

4. In-Process Visual: Five layers of MLI (one module) were normally cut to a template at one time. Quality Control verified conformance to template configuration in addition to verifying that no individual layers had become welded together as a result of the cutting operation.

5. Heat Seal Verification: The basic MLI module was composed of five separate layers of aluminized Mylar film. Several tabs were located along the periphery of the assembly. These tabs were subsequently heat sealed with a thermal impulse heat sealing machine. Prior to the start of each work shift and any time the instrument heat settings were adjusted, process verification tests were performed to verify the integrity of the heat sealing equipment and process. Five test specimens were prepared for process verification. The specimens were inspected to the following criteria:

   - The heat sealed area must not exhibit evidence of receiving uneven heat or pressure during the sealing process. The weld must be continuous.
   - The weld must penetrate the entire joint.
   - No burn-through of shelds was allowed.

   In addition to the above visual inspection, each specimen was tested for strength by loading the test specimen: 90 grams for single layers sealed together and one pound for five layers sealed together.

6. Final Visual Inspection: Visual inspection was conducted during installation of the module assemblies on the test tank temporary flexible posts. Care was exercised to assure the MLI material was not torn at any of the post locations and that uneven loading did not occur at the posts.

c. Quality Verification of Final Assembly: Final acceptance was based on a checkout on the inner purge system after the MLI and outer tension membrane had been installed. The test verified that purge gas flow and distribution was within the required limits.

6.1.10.8 Repair and Maintenance

No standard repair or maintenance procedures were developed.

6.1.10.9 Reliability

The multilayer insulations have not been subjected to any type of reliability analysis. No information is available.

6.1.10.10 Safety

The safety considerations listed were developed during and after the fabrication of one MLI prototype (the 105-inch tank). These considerations must be considered preliminary until a detailed analysis of production processes and the utilization of production articles is completed.

a. Fabrication and Installation: When installing MLI blankets over the supporting posts care must be exercised to insure that the individual layers of the film are not torn. An enlarged hole around the post would provide purge gas leak paths and degraded insulation efficiency.

   Particular attention must be given to keeping the MLI clean and free of contamination during fabrication and installation. Clean gloves must be worn by personnel and area cleanliness must be maintained.

   Additional safety requirements are given in Paragraph 6.1.1.10.

b. MLI Use: The functional testing of MLI systems will include a proof-pressure test of 125 percent of the maximum operating pressure.

   The applied MLI is relatively fragile and damage is easily incurred after the installation is complete. Care should be exercised in the use of MLI to insure that no damage to the insulation surface is sustained.

   The purge gas should be verified to be free of contamination prior to use. When used to insulate hydrogen tanks 2 percent oxygen in the purge gas could combine with leaking hydrogen to form explosive mixtures. Contamination of any gas with the purge would condense on tank surfaces and solidify and block purge passages or provide a pressurizing source that could separate the insulation from the tank when the solidified gases warmed up and vaporized.

   The purge gas should be introduced into the cavities in quantities sufficient to insure that negative pressure does not develop in the MLI. When the sidewall is exposed to cryogenic temperatures the purge gas will contract. A positive pressure within the honeycomb insulation is necessary to insure that minute cracks or openings that are otherwise acceptable will not allow condensable gases to be forced into the purge channels by atmospheric pressure.

   After each cryogenic exposure the exterior surface of the honeycomb insulation should be inspected for damage. Any damage should be repaired and tested prior to another cryogenic exposure.

   Pressure-relieving devices should be provided to insure that the purge gas pressure does not exceed the design allowable.

6.1.10.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. The following hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost: 16 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 14 weeks.

Subassembly - 6 weeks.

Installation - 5 weeks.

Checkout - 5 weeks.

c. Weight: The total as-installed weight is 0.215 lb/ft^2 broken down as follows:

1. Multi-layer insulation, 90 layers (MB0135-034) - 0.167 lb/ft^2
2. Aluminum support screen - 0.032 lb/ft^2
3. Tension membrane - 0.016 lb/ft^2

d. Thermal Performance: The Q of this system is 0.10 $Btu/hr/ft^2$. The PK of this system is 8.78×10^{-5} $Btu/lb/hr-^oF-ft^4$.

6.1.11 Multi-Layer Insulation, Flow-By Purge

6.1.11.1 Description

An MLI system with a flow-by purge was proposed for use on the Chemical Interorbital Shuttle (CIS) to provide thermal protection for cryogens in a space environment (SD 72-SA0042-2, Drawing V7-953596). The MLI is a spacerless system similar in description and performance to the MLI system described in Paragraph 6.1.10.1.

The basic insulation concept consists of a purge gap, MLI support screen, MLI, and a purge bag as shown in Figure 6.1.11.1-1. The MLI is spaced away from the tank wall to form a purge annulus. A sealed bag is provided on the outside of the MLI to enclose the MLI within a purged environment. Pre-conditioning and drying of the MLI is accomplished by flowing purge gas through the annulus past the inner MLI surface. It should be noted that an adequate venting system also must be provided to optimize the thermal performance of the MLI in space.

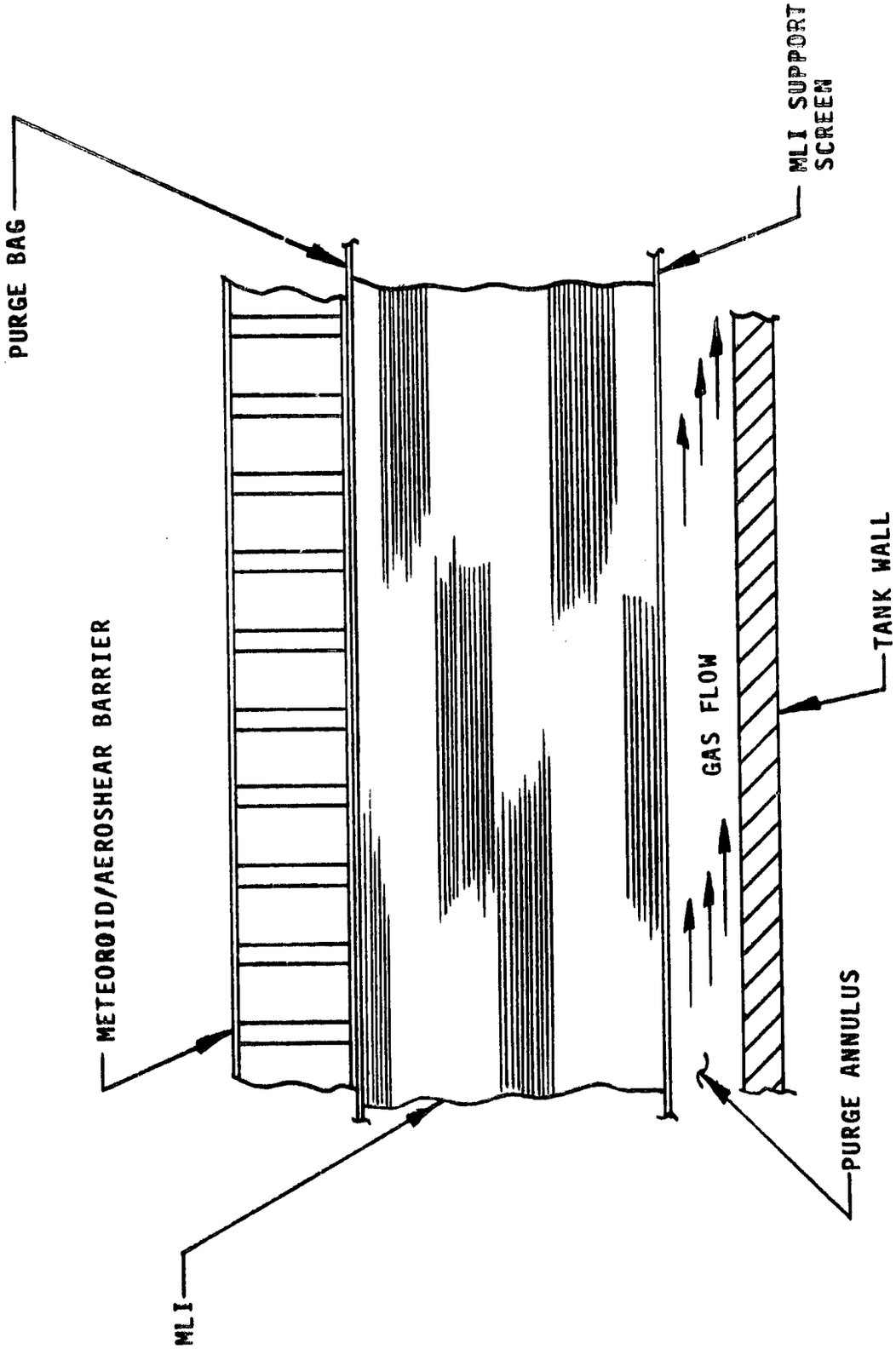


Figure 6.1.11.1-1 MLI - Flow by Purge

6.1.11.2 Application

a. Utilization: This MLI system was selected for the CIS study because it provided minimum weight with satisfactory thermal performance. This system can be utilized for any vehicle application. It is particularly applicable to large vehicles that are subject to aerodynamic loading during launch and to vehicles that are normally transported inside another carrier.

b. Performance Characteristics: Thermal performance of this system is the same as for the previous system. Analysis of the flow-by purge system indicates that maximum concentration of water vapor can be reduced to less than 30 percent of original concentration in approximately four hours of purge time and to less than 10 percent after seven yours.

c. System Limitations: This system was designed to meet the CIS study performance and operational models. It can be utilized for any application requiring MLI.

d. Design Problems: This system has not been applied to a vehicle. Problems are the same as described in the previous section.

e. Design Verification Tests: No tests have been conducted on the flow-by concept. Tests related to removal of moisture from aluminized Mylar are reported in SD 71-263.

6.1.11.3 Thermal Performance

The thermal performance characteristics of this insulation system are given for a tank containing LH_2 which is exposed to simulated ground-hold, launch, orbit, and reentry environments. These characteristics for an MLI with a flow-by purge are approximately equal to those given previously for the MLI with flow-through purge.

An effective thermal conductivity (K_{MLI}) of 5.21×10^{-5} Btu/hr-ft-^{o}F was predicted for orbital performance. The predicted orbital heat flux is 0.20 Btu/hr-ft^2. The effective K_{MLI} = 0.060 Btu/hr-ft-^{o}F during ground hold. The predicted overall heat flux will be 140 to 240 Btu/hr-ft^2 depending on flow velocity through purge channel during ground-hold operation.

6.1.11.4 Structural Performance

Significant factors affecting the structural integrity of this insulation system are identical to those given in Paragraph 6.1.10.4 for the flow-through purge insulation system.

6.1.11.5 Material and Processes

The MLI system was proposed for use on CIS to provide thermal protection for cryogenics in a space environment. No material and processes information was developed.

6.1.11.6 Manufacturing

No manufacturing information is available on this system.

6.1.11.7 Quality Assurance

This design did not reach production status during the course of the Saturn S-II program. No quality control procedures were therefore established for the total insulation system. Quality assurance provisions for the MLI portion of the design are included in Paragraph 6.1.10.7.

6.1.11.8 Repair and Maintenance

No repair or maintenance procedures were developed.

6.1.11.9 Reliability

This insulation has not been subjected to any type of reliability analysis. No information is available.

6.1.11.10 Safety

This insulation system has not been fully developed. No detailed hazard analysis has been conducted and no overall safety recommendations can be made. MLI has been analyzed and some experience gained in fabrication, installation, and utilization. As a result safety recommendations can be obtained from Paragraph 6.1.10.10. It is not expected that a different combination of components will materially alter the recommendations originally made on a single component but overall evaluations cannot be made before an analysis.

6.1.11.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost. No data are available on these costs.

b. Schedule: The schedule flow times for this insulation system are:

Procurement - 14 weeks.

Subassembly - 6 weeks.

Installation - 5 weeks.

Checkout - 5 weeks.

c. Weight: The total as-installed weight is 0.215 lb/ft^2 broken down as follows:

1. Purge bag = 0.016 lb/ft^2
2. MLI, 90 layers (MB0135-034) = 0.167 lb/ft^2
3. Support screen = 0.032 lb/ft^2

6.1.12 Meteoroid Protection System

6.1.12.1 Description

This system was proposed as a meteoroid/erosion barrier over the MLI on the Chemical Interorbital Shuttle (SD 72-SA0042-2). This system is similar in performance and design to that of the erosion barrier described in Paragraph 6.1.9.1. The barrier serves to protect the MLI from thermal and pressure loads during boost and, together with the MLI, protects the propellant tank from micrometeoroid impact while in orbit.

The barrier concept consists of individually supported panels of sandwich construction as shown in Figure 6.1.12.1-1. A polyimide panel design is shown; however, a titanium panel design also was proposed.

a. Polyimide Panel: Polyimide facing sheets are bonded to HRP honeycomb core to form a rigid sandwich structure (V7-953595 and V7-953596). Gaps are provided between adjacent panels and slots or oversize holes are provided at attach points to accommodate axial and circumferential tank movement and expansion and contraction of the panels. Closeout strips (Figure 6.1.12.1-2), are provided at panel joints to cover gaps. Figure 6.1.12.1-3 shows a panel support post concept.

b. Titanium Panels: Titanium facing sheets are diffusion-bonded to titanium honeycomb core to form a rigid sandwich structure. The attachment and closeout concept would be similar to that shown for the polyimide panel design.

6.1.12.2 Application

a. Utilization: Meteoroid protection must be provided for critical structural components on all vehicles in space. This is particularly true for cryogenic tanks which can suffer immediate catastrophic damage or be subject to subsequent failure from induced meteoroid damage. Protection is also required for external insulation systems since a strike may impair thermal performance.

The extent to which each vehicle must be protected depends on its mission trajectory with respect to galactic location. Reference 19 presents these criteria. References 51 and 52 present interesting study results.

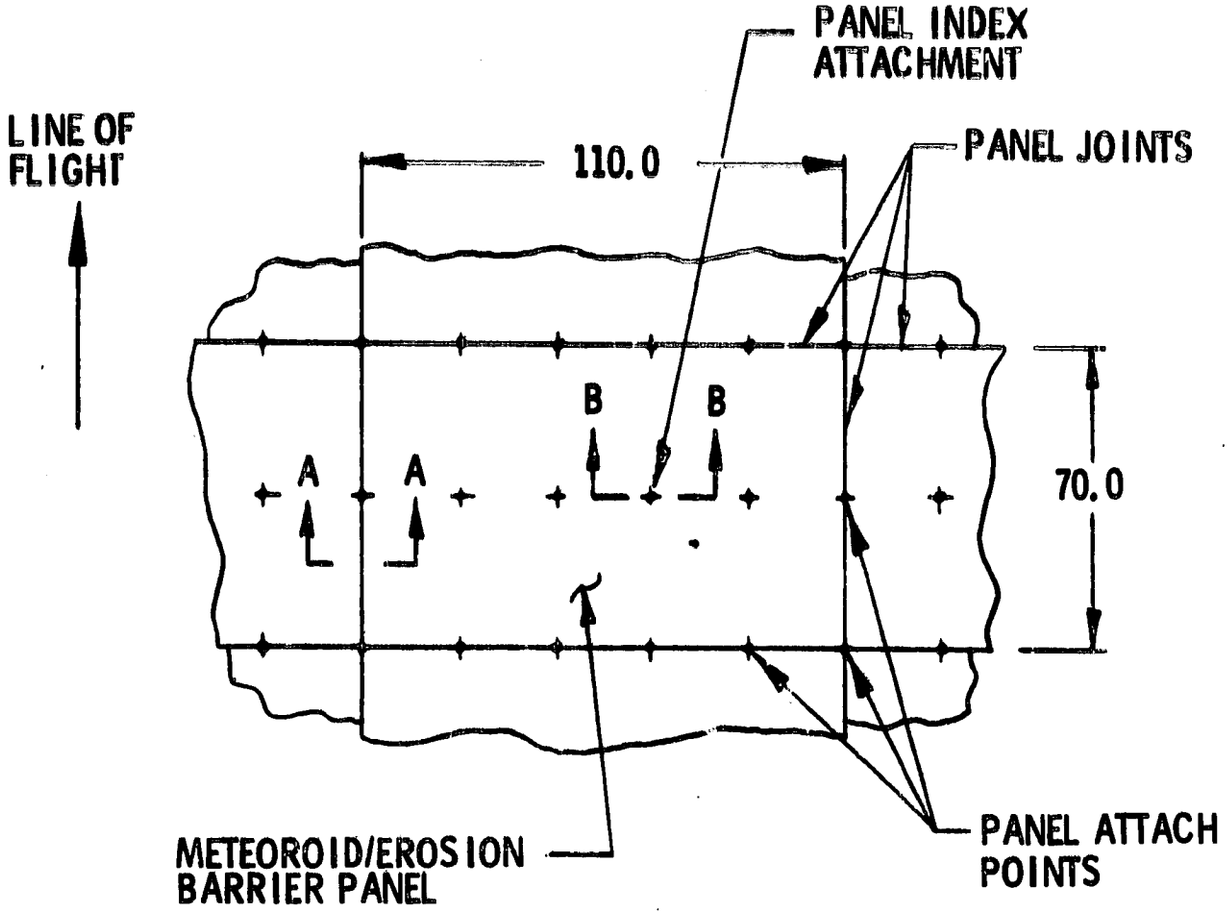


Figure 6.1.12.1-1. Meteoroid Erosion Barrier Concept - View Looking Inboard at LH_2 Tank Sidewall

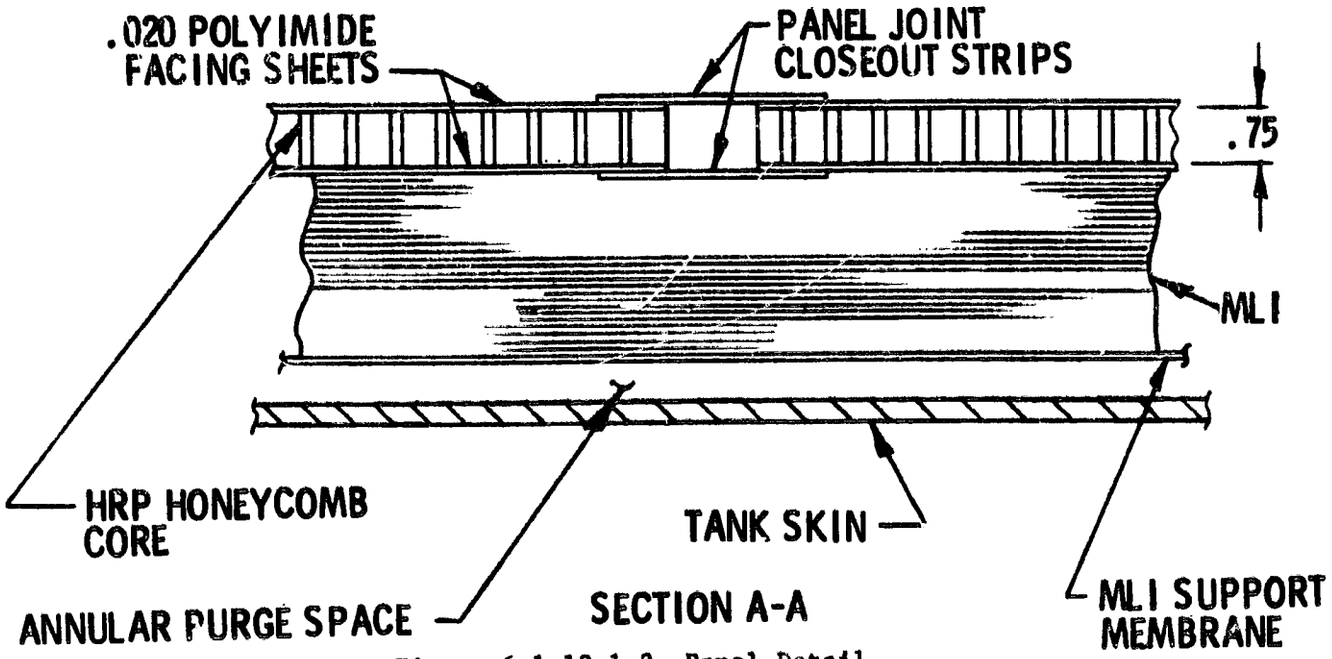


Figure 6.1.12.1-2. Panel Detail

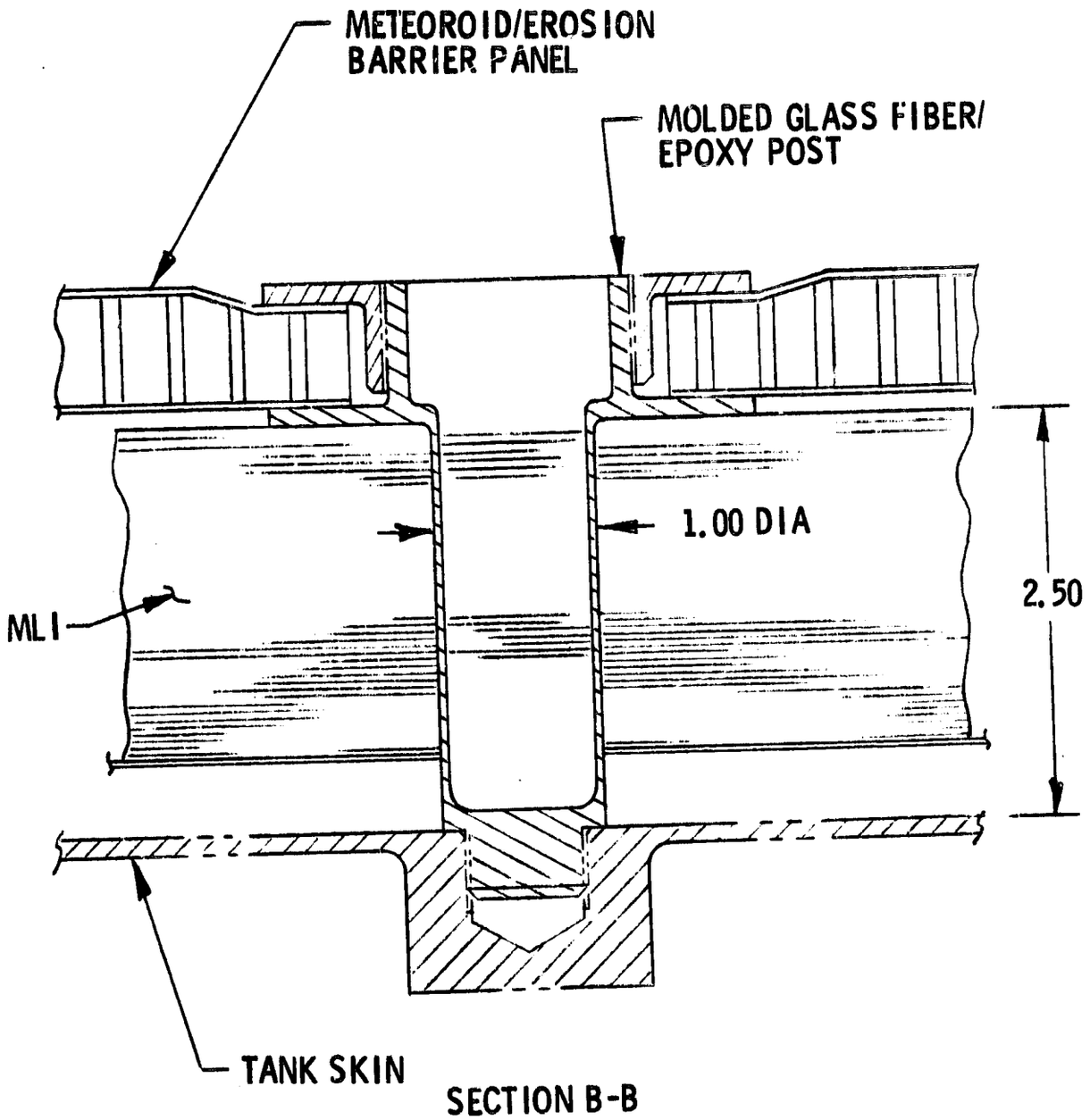


Figure 6.1.12.1-3. Panel Attachment

The design shown in Figure 6.1.12.1-1 was proposed for a large Saturn-class vehicle utilizing an MLI system for the LH_2 tank. The erosion barrier also functions as a dual bumper meteoroid barrier.

b. Performance Characteristics: This design has not been fabricated as there are no data on performance.

c. System Limitations: This design was proposed for a CIS stage. Materials (titanium or polyimide) and attachment dimensions are selected based on flutter analysis in launch. It is limited to the conditions and environment of that mission, including induced aeroheat and pressure during launch and the trajectory and meteoroid exposure periods in cislunar space. Shielding criteria are listed in Tables 6.1.12.2-1 and 6.1.12.2-2.

d. Design Problems: The feasibility of this design was demonstrated in the development program described in Paragraph 6.1.9.

e. Verification Tests: The analytical techniques discussed were developed on the basis of a test program conducted by NR and described in Reference 49.

Twenty-five percent penetration of the tank wall was assumed acceptable. This has been used in prior studies and verified by experience on Apollo service module where impact tests on pressurized LH_2 tank sections confirmed that greater damage was required to cause failure.

6.1.12.3 Thermal Performance

The thermal performance characteristics of the aeroshear/meteoroid barrier over MLI insulation composites were worked out for a series of different insulation systems for a CIS configuration are given in SD 71-245-4. A sample result of the analysis is shown in Figure 6.1.12.3-1 for the boost phase. It is particularly important to note the expected temperature of the meteoroid and erosion barrier, the MLI, and the fiberglass felt. If the MLI (Mylar) gets above about 200 F, it will melt and for this reason a gap is required outside the MLI. The reason for this is shown in Figure 6.1.12.3-2. The analysis of the exterior erosion barrier which is the item of primary concern for this section is shown as Zones 1 and 2.

6.1.12.4 Structural Performance

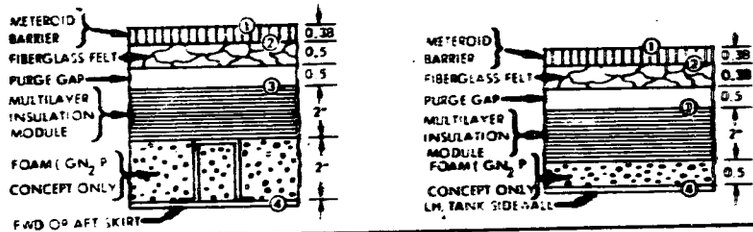
Significant factors affecting the strength of this insulation system are identical to those given in Paragraphs 6.1.9.4 and 6.1.10.4.

6.1.12.5 Material and Processes

The meteoroid and erosion barrier over MLI was not produced in accordance with any material or process specification requirements and, therefore, no procedures or techniques were established.

6.1.12.6 Manufacturing

No manufacturing information is available for this system.

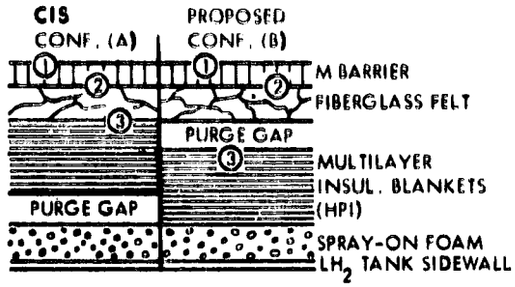


LOCATION	ATTACHMENT FITTING ZONES	SHOCK WAVE ZONES	GN_2 PURGE CONCEPT				GHE PURGE CONCEPT			
			BARRIER SURFACE ①	FIBERGLAS FELT ②	BLANKET SURFACE ③	STRUCTURE ④	BARRIER SURFACE ①	FIBERGLAS FELT ②	BLANKET SURFACE ③	STRUCTURE ④
FORWARD SKIRT	A		957	693	280	90	956	692	286	104
	B		684	497	219	90	683	495	169	104
		C	1261	964	366	90	1261	964	262	104
LH_2 TANK SIDEWALL	B		624	485	166	-422	615	461	-38	-422
		B	1009	814	286	-422	1005	799	74	-422
		G	895	713	248	-422	890	696	8	-422
AFT SKIRT (INSULATED AREA)	B		549	432	210	94	648	480	156	105
		E	1214	912	344	95	1211	910	257	106
AFT SKIRT AND INTERSTAGE (UNINSULATED AREA)	B		-	-	-	310	-	-	-	310
		E	-	-	-	970	-	-	-	970

Figure 6.1.12.3-1. Preliminary Aerodynamic Peak Temperature of CIS Sidewall Insulation System During Boost - CIS Aft Configuration

Space Division
North American Rockwell

NOTE:
1. INSULATION SYSTEM PURGED WITH GN_2
2. 1/2 INCH THICK FOAM LAYER ON LH_2 TANK
3. AERODYNAMIC HEATING RATES USED WERE FOR SHOCK WAVE REGION B.



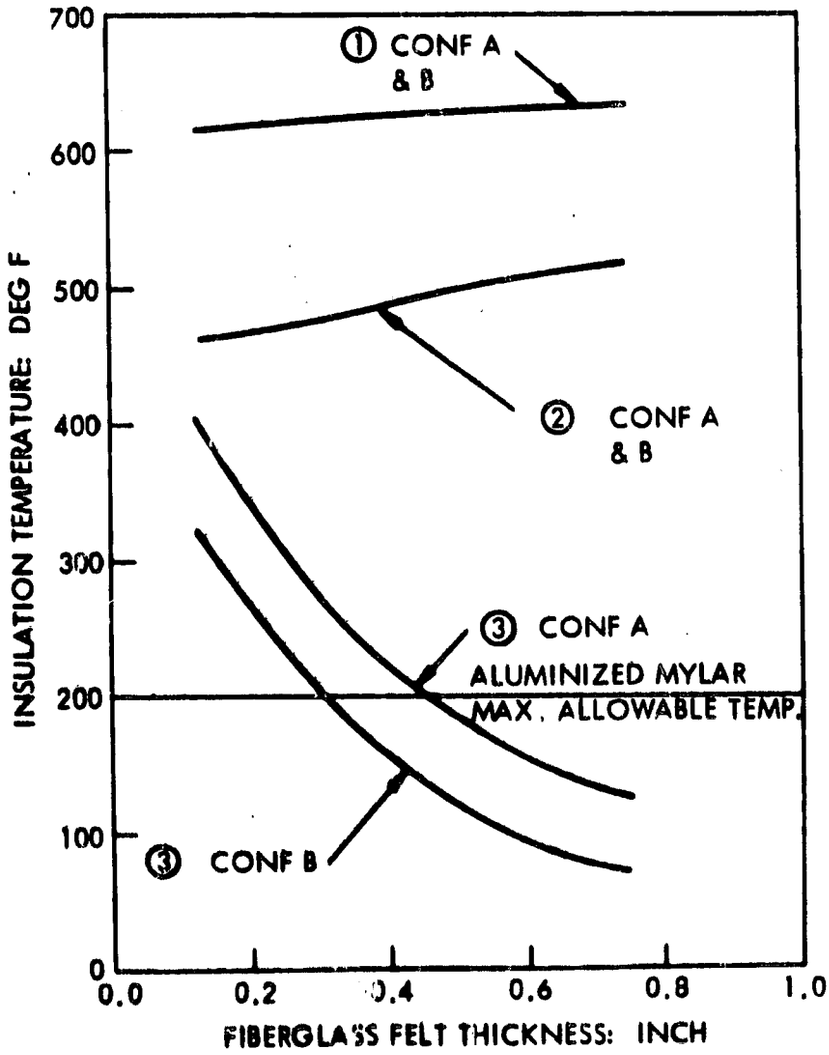


Figure 6.1.12.3-2. LH_2 Tank Sidewall Insulation Peak Temperatures During Boost Versus Fiberglass Felt Thickness

Table 6.1.12.2-1. Meteoroid Shielding Criteria

Parameter	Value
Meteoroid Data	
Environment from NASA	TMX - 53957
Density	0.5 gm/cc
Velocity	20 km/sfc
Comet	Average yearly flux
Design	
Probability of no tank failure	0.995
Allowable tank wall penetration	25%
Aft end of CIS shielded by engine module	-
Drop tank always shielded by propulsion vehicle	-
Mission Time	
CIS - separated	
At 270 n mi earth orbit	60 days
At 180 n mi earth orbit	455 days
At 60 n mi moon orbit	178 days
CIS - mated	
At 180 n mi earth orbit	616 days
Drop tank - mated	
At 180 n mi earth orbit	100 days

Table 6.1.12.2-2. Shield Factors

Element	CIS				Drop Tank Mated
	Separated		Mated		
Vulnerable area (ft^2)	3832	3832	3832	3020	6308
Time of exposure (days)	60	455	178	616	100
Orbit/planet ratios	270/3444	180/3444	60/938	180/3444	180/3444
Shield factor	0.90	0.85	0.872	0.85	0.85

6.1.12.7 Quality Assurance

This design did not reach production status during the course of the Saturn S-II program. No quality control procedures were therefore established for the total insulation system. Quality assurance provisions for the MLI portion of the design are included in Paragraph 6.1.10.7.

6.1.12.8 Repairs and Maintenance

No standard repair or maintenance procedures were developed.

6.1.12.9 Reliability

No failure mode effects analysis or other reliability information is available.

6.1.12.10 Safety

This insulation system has not been fully developed. No detailed hazard analysis has been conducted and no overall safety recommendations can be made.

Some of the components of this system such as HRP honeycomb and MLI have been analyzed and experience gained in fabrication, installation, and utilization. As a result safety recommendations can be obtained from the other insulation systems that utilize these components. It is not expected that a different combination of components will materially alter the recommendations originally made on a single component but overall evaluations cannot be made without the analysis.

6.1.12.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and are an indicator of relative cost. No data are available on these costs.

b. Schedule: The schedule flow times for this insulation system are not available.

c. Weight: The total as-installed weights are:

1. Titanium honeycomb panel and face sheets	-	0.557 lb/ft^2
2. MLI, 90 layers (MB0135-034)	-	0.167 lb/ft^2
3. Support screen	-	0.032 lb/ft^2
Total	-	0.756 lb/ft^2

1. Polyimide face sheet, HRP honeycomb core	-	0.470 lb/ft^2
2. MLI, 90 layers (MB0135-034)	-	0.167 lb/ft^2
3. Support screen	-	0.032 lb/ft^2
Total	-	0.669 lb/ft^2

d. Thermal Performance: The Q of this system is 0.1 Btu/hr/ft^2. The PK of this system is 29.0 x 10^{-5} Btu/lb/hr-^{o}F-ft^4 (titanium) and 21.3 x 10^{-5} Btu/lb/hr-^{o}F-ft^4 (polyimide).

6.2 CRYOGENIC TRANSFER

6.2.1 Vacuum Jacket

6.2.1.1 Description

The vacuum jacket insulation system is used on the cryogenic propellant transfer and vent lines of the Saturn S-II stages (MC271-0011). A low-loss transfer of cryogenic fluids is attained because an annular evacuated space minimizes two components of heat transfer – solid conduction and gaseous convection. Heat is transferred across the vacuum insulation by the mechanisms of radiation across the evacuated space and gaseous conduction through the residual gas in the evacuated space. Additional heat is transferred at components such as spacers and end flanges.

The vacuum-insulated line concept consists of an inner and an outer shell, with the space between sealed and evacuated. The configuration shown in Figure 6.2.1.1-1 is a welded assembly consisting basically of an inner and an outer tube, bellows, spacers, supports, and end flanges. A vacuum service valve is provided to effect evacuation of the space between the inner and the outer tube. A thermocouple gauge effects periodic vacuum checks. The bellows accommodate thermal contractions and structural deflections. Spacers maintain the space between the inner and the outer line. Simple low-performance bolted flange connections are used at line joints.

6.2.1.2 Application

a. Utilization: Vacuum-jacketed lines are used primarily in cryogenic applications where low heat transfer to the cryogenic fluid is required. This type of transfer line is applicable to launch vehicles such as the S-II, to space orbiting vehicles, and to ground storage transfer systems.

b. Performance Characteristics: The insulating ability of vacuum-jacketed transfer lines is achieved by reducing the solid conduction and convection heat transfer mechanisms through evacuation of the gases from the jacket area. Good thermal performance requires an annular vacuum below 1.33×10^{-2} newton/meter^2 (10^{-4} Torr).

   Vacuum-jacketed LH_2 and LOX fluid transfer lines have been successfully used on all S-II's flown. The quality of the propellants has been maintained within the engine start box requirements.

c. System Limitations: This system was designed and developed to meet the NPSH requirements of the feed pumps. The engine start requirements limit the LH_2 engine temperature to -420.5 F. Line vacuum is limited to 200μ Hg or below, with a maximum allowable leakage rate of 5μ Hg per day. The LOX pump discharge temperature is limited to 100μ Hg or below, with a maximum vacuum leakage of 5μ Hg per day.

d. Design Problems: Unintentional loss of vacuum or latent defects that may cause insulation loss are primary design concerns. During the S-II program,

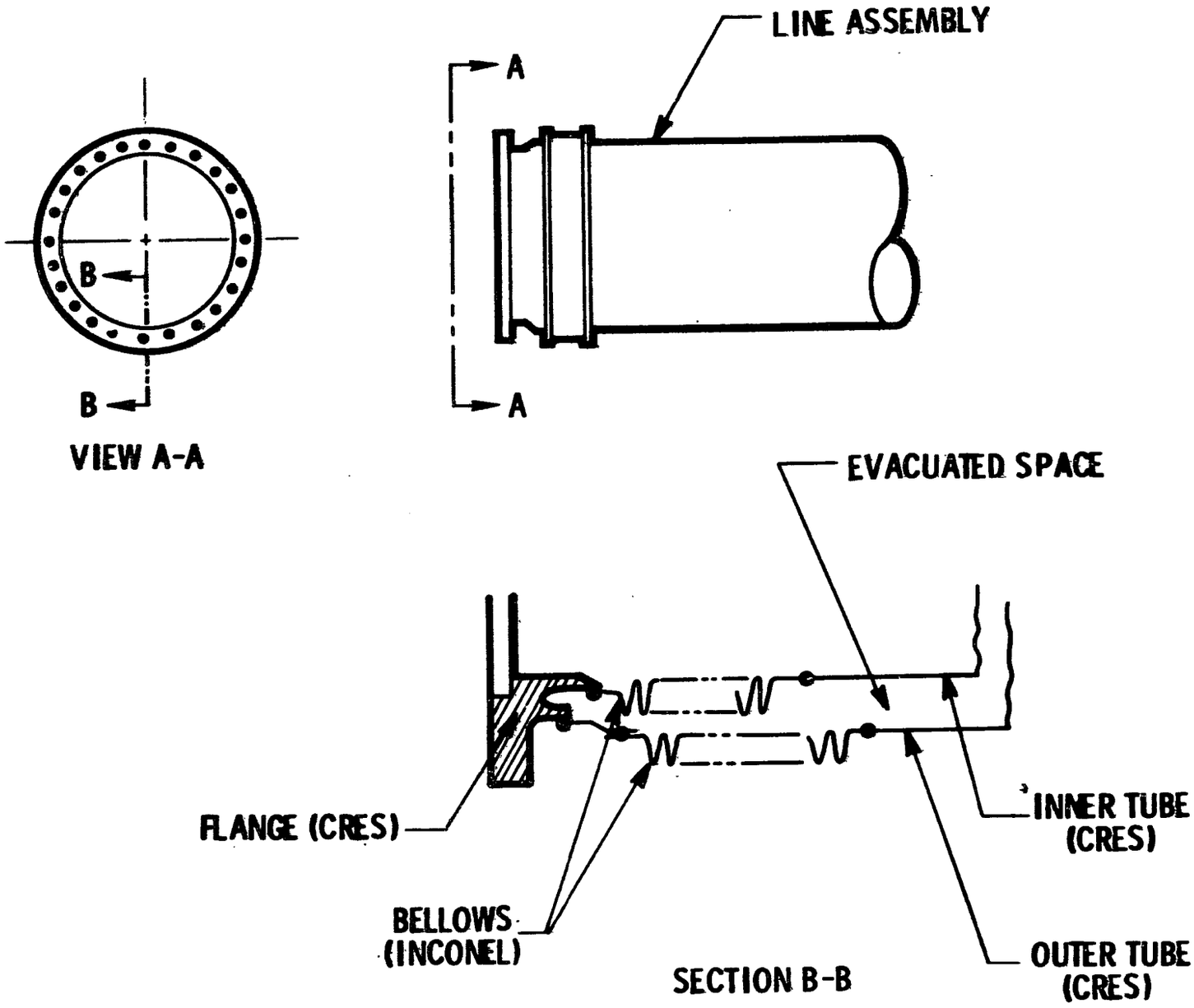


Figure 6.2.1.1-1. Vacuum-Jacketed Line Assembly

jacketed ducts experienced vacuum loss due to the following: annulus contamination, pressure carrier implosion, faulty thermocouple installation, thermocouple failures, rupture disc assembly, welds, parent metal, and evacuation valves. These are discussed in the following paragraphs. In all cases, the problems were resolved.

Annulus Contamination

Problem: Vacuum loss can occur as the result of the entry of certain substances into the annulus. After entry, material that has previously absorbed objectionable gases will readily outgas in a vacuum and cause decay that may be immediate or continue for some time. Contamination is typically caused by incompatible grease, where "vacuum" grease was required, entry of oil in the annulus because of improper vacuum pump operation, and inadvertent opening of the evacuation valve or rupture disc. Supplier problems stemmed mainly from nonmetallic jacket standoffs that entrapped cleaning fluids, causing excessive pump-down periods or rapid vacuum decay.

Resolution: The standoffs in the jacketed LH_2 recirculation ducts were redesigned to allow free passage of all cleaning media during assembly and also to provide a direct evacuation path. The vacuum pump was redesigned. The pump-down times were also extended to provide for maximum outgassing in minimum time, and the evacuation procedure was revised by adding a carbon dioxide purge to ensure that all residuals would be condensible at cryogenic temperatures.

Pressure Carrier Implosion

Problem: During an operational check of the LH_2 feed duct, the vacuum-jacket annulus was inadvertently overpressurized (20 psi), which collapsed the pressure carrier. Subsequently, the duct was pressurized to 30 psi during a system test, which "ballooned" the collapsed duct and caused 1 fold in the duct wall to form, tear, and allow pressure to enter the annulus and force the rupture disc to burst.

Resolution: Specifications were revised to preclude accident or over-pressure. A safety relief valve (1 psi) was added to the evacuation equipment to prevent annulus overpressurization during leak-check cycles. The duct wall thickness was increased.

Faulty Thermocouple Installation

Problem: Any instrumentation attached to a vacuum jacket through a threaded connection requires absolute sealing to preclude loss of vacuum. Threaded sections, both male and female, must be protected at all times before assembly and appropriate sealing material such as Mylar tape must be applied to the male thread before assembly.

Thermocouple Failures

Problem: Two major problems are separation of the gauge tube from the mounting boss and breakage of the filament wire junction weld. Breakage will cause sudden vacuum loss and, under certain conditions, could also cause implosion or bursting of the rupture disc.

Resolution: The thermocouple gauge tube, originally made of brass material, was changed to CRES 321, resolving the breakage problem. The filament wire welding process was revised, as was the filament pattern to make it symmetrical (it has been asymmetrical).

Rupture Disc Assembly

Problem: The rupture disc assemblies in S-II ducts use two types of discs; one is an 0.008-inch-thick disc with a single coined diagonal slot, coined to a thickness of 0.0013 inch, and the other is a domed spherical segment 0.002 inch thick. Both types were made of CRES 321, and both suffered from random corrosion.

Resolution: The primary factor in resolving the corrosion problem was to change the material to INCO 600.

Weld

Problem: Vacuum leakage through welds can be caused by cracks or porosity in the weld or in the adjacent tubing, bellows, or interface component. Cracks can occur if the weld is allowed to cool too slowly, the mating parts of the butt joint are misaligned, or the trim is not centered in the nugget.

Another weld leakage problem of major concern is related to the longitudinal butt weld of a bellows ply in a multiply assembly. Each ply is separately formed into its sized-tube configuration, and two, three, or four separate, contoured segments, each in turn butt-welded to the other, form a tube (i.e., the ply). The concern in this application was that during the forming of the bellows rather large microcracks were being generated in the butt welds at the crest of the convolution.

Resolution: Nondestructive test methods were established to ensure an accurate nugget location. Improved chill rings were incorporated into the production weld techniques, as were tools to properly size and locate adjacent parts during welding.

The bellows' longitudinal butt-weld cracking was resolved by revising fabrication sequencing to eliminate the crack initiator step, and the number of welds was reduced to one per ply by cutting the stock material so that the longitudinal axis was normal to the roll direction.

Parent Metal

Problem: Vacuum loss through a parent metal leak path is related to flange and jacket penetrations that are machined from bar stock or forgings where thin sections lie approximately normal to the grain direction or roll direction. If this material had inclusions these may open up after exposure to heat resulting from welding or other operations.

Resolution: The solution to this condition is to use a material that will not allow full stringers to form. Specific repair procedures were applied by welding closed the leak path.

Offset and Peaking - Thin Wall Tubing Butt Welds

Problem: A crack failure of a circumferential weld in a thin-walled vent line resulted partially from a peaking-offset discontinuity in the butt weld. Stress analysis procedures established that such discontinuity would produce stress concentrations at these points that could significantly shorten fatigue life.

Resolution: A unique inspection tool was devised by NR to inspect the butt welding of these pressure carriers.

Flow-Induced Vibration

Problem: Bellows flow-induced vibration is a basic consideration in assessing the expected life of a pressure-carrying duct, vacuum-jacketed or otherwise.

Resolution: The LOX tank fill and drain line bellows problem was solved by changing from one-ply to three-ply bellows, and all bellows were lined. Subsequent analysis (post-AS-502 ASI failure) showed that the liners were not necessary. At that time, redundancy was thought necessary because a thorough understanding of the phenomena was not known. In either case, a flow test was required to verify the fix and obtain pressure-loss data.

The subsequent acoustic resonance failure of the S-II-9 flex hose resulted in another analytical and test program. A key finding relative to resonance inducement was that the cause of the acoustic mode was the purge medium, not the end-use medium.

e. Design Verification Tests: A series of tests was conducted to verify the structural and thermal adequacy of the feedline (LH_2 and LOX) designs. These tests are described in MC271-0010 and MC271-0011).

6.2.1.3 Thermal Performance

The thermal performance characteristic for vacuum-jacketed cryogenic transfer lines is the heat transfer rate from the hot external environment to the cryogen flowing inside the line. Heat is transferred from the environment to the hot outer jacket by radiation and by convection; across the annular space by radiation from the hot outer jacket to the cold inner line, by gaseous

conduction through the residual gas within the annular space, and by solid conduction through spacers and instrumentation bosses; and from the inner line to the cryogen by convection. This rate of heat transfer is needed to evaluate liquid temperatures so as to ensure that engine performance and ground-hold propellant conditioning requirements can be met.

The design thermal performance of the vacuum-jacketed LH_2 and LOX feed and recirculation lines for the S-II vehicles was established by the Model Specification (SID 61-361). The specified maximum allowable heat transfer rate was 30 Btu/hr-ft^2 for the LH_2 lines and 45 Btu/hr-ft^2 for the LOX lines. These values include the heat leak through the spacers and instrumentation bosses, but exclude heat leak to the cryogen through end flanges, valves, and appurtenances. These bosses were separately analyzed. To achieve the design heat transfer rate for the LH_2 lines, the surfaces surrounding the annular space (both sides of the vacuum area) should be a polished, low-emittance metal coating such as gold or aluminum. For the LOX lines, standard piping materials may be used to meet the specified allowable rate.

The actual thermal performance of the vacuum portion of the S-II vacuum-jacketed lines was degraded or excessive compared with the design ideal. This degradation was due primarily to heat leak through residual, noncondensible gases in the annulus. To meet the overall or combined requirement, the heat leak through flanges, valves, and appurtenances was reduced to tolerable levels by foam insulating these components. The thermal design details are discussed in Paragraph 7.3.2.1. The thermal degradation due to gaseous conduction was reduced by implementing elaborate back-fill and evacuation procedures.

6.2.1.4 Structural Performance

The complete assembly — propellant carrier (inner shell) and jacket (outer shell) — must continue to function while subjected to pressure loads, vibrational loads, differential temperature, and motion of one interface relative to another. The propellant carrier is the primary load-carrying structure while the vacuum jacket is subjected to the collapsing pressure resulting from evacuation of the inner space. Strain compatibility between the inner and outer shells is maintained by bellows in the outer shell, as shown in Figure 6.2.1.1-1.

To resist adequately buckling due to collapsing pressure, a corrugated outer jacket was chosen for the S-II design. For the elbow design, a corrugated structure with longitudinal stiffeners was selected to prevent excessive translational motion while maintaining adequate resistance to buckling. A corrugated elbow without longitudinal stiffeners tends to straighten excessively when subjected to external pressure.

6.2.1.5 Materials and Processes

All vacuum jacket lines of the S-II were fabricated by subcontractors to NR procurement specifications. The construction materials depended on thermal

and structural loads. However, in general, austenitic grade stainless steels and nickel base alloys were used. Typical materials are as follows:

Outer Jacket and Pressure Carrier	321 CRES, 304 CRES, INCO 718
Bellows	321 CRES, INCO 718
Rupture Discs	INCO 600
Gimbal Joints and Pins	A-286
Bosses and Flanges	304 CRES, 321 CRES

Manufacturing processing also varied by the subcontractor. However, all lines were of a totally welded construction, with the outer jacket and pressure carrier being roll-formed sheet stock with a longitudinal butt weld. In the case of small-diameter lines, seamless tubing was used. Gimbal joints, flanges, and bellows were joined to the basic line by butt welds or unique welded joints dictated by double-wall bellows design. All welds were 100 percent X-ray and fluorescent penetrant inspected. Wherever possible, weld planishing was performed to improve mechanical properties and fatigue life.

6.2.1.6 Manufacturing

The manufacturing breakdown is not available because the LH_2 vacuum-jacketed lines were manufactured by a company specializing in this product.

6.2.1.7 Quality Assurance

All vacuum-jacketed lines (Figure 6.2.1.1-1) used on S-II were supplied by subcontractors to NR. Procurement specifications established the engineering and quality assurance requirements for each line assembly. MC271-0010 for liquid oxygen feedlines was typical of these specifications. Prior to fabrication of production line assemblies, the supplier was required to demonstrate the capability of his tooling, equipment, and personnel by producing prototype assemblies which were subjected to qualification and reliability testing. Extensive testing was conducted to verify the functional and operational characteristics of the line assemblies. Following successful supplier qualification, the quality of each production line assembly was verified as noted.

a. In-Process Source Inspection: A resident source inspector was present in the supplier facility during all production operations.

   1. Raw Material Certification: Certification data for all metallic materials were reviewed for specification compliance.

   2. Equipment Calibration and Certification: It was verified all applicable equipment was within current calibration and that all production equipment was as employed during the qualification phase of production.

3. Operator Certification: Only certified technicians were employed to perform critical production operations such as welding and machining.

4. Dimensional Inspection: Major dimensional checkpoints were established for all production operations.

5. Radiographic Inspection: Where accessible, all welds were radiographically inspected. Welds in the outer vacuum jacket which were impossible to inspect radiographically were visually inspected with a ten-power scope and helium leak-checked by mass spectrometer.

b. Final Product Acceptance Tests: Prior to delivery and as a condition of acceptance, the supplier subjected each production unit to the following acceptance tests:

1. Visual Inspection: Each assembly was inspected to verify compliance with the procurement specification with respect to material, dimensions, weight, construction, identification, marking, and quality of workmanship.

2. Proof Pressure Test: The assembly was pressurized to 140 psig with gaseous nitrogen and held for three minutes.

3. Operational Test: The assembly was mounted in a test fixture and stressed to verify the ability to undergo the structural movements required by specification.

4. Vacuum Jacket Pressure Test: The vacuum chamber was stabilized at a pressure of 10 ± 5 microns at 68 ± 5 F. It was verified that the maximum pressure rise (vacuum decay) did not exceed 150 microns in 30 days.

5. Pressure Carrier Leakage Test: While evacuated to 10 microns in the vacuum jacket, the internal line pressure was raised to 88 psig with helium. External line temperature was then varied from ±160 F to -300 F while monitoring vacuum jacket pressure. It was verified the vacuum returned to 10 ± 5 microns at room temperature, following the temperature excursion.

6. Cleanliness: The line assembly was verified to meet the LOX service cleanliness level established by NASA Specification MSFC-SPEC-164.

6.2.1.8 Maintenance and Repair

As noted in Paragraph 6.2.1.1, a major drawback of this insulation concept is sensitivity to damage. Extreme care must be exercised to prevent damage to vacuum-jacketed lines during transportation, installation, and storage. Of particular importance is the care of bellows — because of their thin wall construction, minor dents can result in a vacuum loss. Protective covers are mandatory during all inoperative periods. Little in-place repair can be performed on vacuum-jacketed lines. With the exception of rework for minor corrosion, all repairs are made by removal and replacement.

6.2.1.9 Reliability

One failure mode, vacuum loss, is identified; however, this mode will result from several causes, such as line structural failure, evacuation valve leakage, or leakage at any subcomponent of the line assembly. FMEA results are presented in Table 6.2.1.9-1.

Table 6.2.1.9-1. FMEA — Vacuum Jacket Insulation

Subsystem or Component	Failure Mode	Mission Effects Remarks
Feed and System Recirculation	Loss of Vacuum	Loss of recirculation capability, resulting in loss of engine to start or perform properly. Possible mission loss.

6.2.1.10 Safety

a. Fabrication and Installation: During the fabrication of vacuum-jacketed lines, the metalworking processes involved should be guided by the applicable sections of Industrial Safety Standards.

Particular care should be exercised in maintaining the cleanliness of components of vacuum-jacketed lines. When any form of contamination is introduced into the vacuum annulus, it is difficult or impossible to remove.

Before assembly of the inner and outer jackets of these lines, they should be separately tested, inspected, and verified as acceptable.

Parts and assemblies of vacuum-jacketed lines should be shipped or moved in individually designed containers.

During the installation of these lines, the expansion bellows should be protected from damage by guards.

b. Insulation System Use: The bellows at any other easily damaged component of the vacuum-jacketed line should be protected from damage when there is any activity in the vicinity of the line.

Any time a vacuum-jacketed line is pressurized above ambient, it must be restrained to prevent overextension of the bellows.

The insulation efficiency of these lines depends on the maintenance of the vacuum between the inner and outer jackets. The vacuum valves must be leak-tight and a means provided to measure the degree of vacuum when the line is installed.

A burst disc in the outer jacket prevents overpressurization in case cryogens leak into the annulus. This disc must be protected from damage, remain free of contamination, and be free of leakage.

6.2.1.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the systems relative cost: 458 hours per foot of length for 8-inch diameter.

b. Schedule: The schedule flow times for the insulation system are as follows:

Procurement - 104 weeks

Subassembly - No NR data

Installation - No NR data

Checkout - No NR data

c. Weight: The total as-installed weight is 6.89 pounds per foot of length.

d. Thermal Performance: The Q of this system is 30 Btu/hr/ft^2; ρK is 0.198 Btu/lb/hr-^{o}F-ft^4

6.2.2 Vacuum Jacket Plus Multilayer Insulation

6.2.2.1 Description

The vacuum jacket plus multilayer insulation (MLI) concept was proposed for the Chemical Interorbital Shuttle (CIS) study (V7-953596, SD72-SA0042-2), as the insulating system for the cryogenic propellant transfer lines. The vacuum jacket is an effective thermal insulation for ground and boost operations (Paragraph 6.2.1.1), and the MLI provides additional resistance against radiant energy and is most effective during space operations.

The concept for the vacuum-jacketed line with MLI is illustrated in Figure 6.2.2.1-1. The vacuum-jacketed design is described in Paragraph 6.2.1.1, the MLI consists of single aluminized Mylar-embossed (SAME), which is added in concentric layers around the vacuum jacket. For a more detailed description of MLI, see Paragraph 6.1.10.1.

6.2.2.2 Application

a. Utilization: Vacuum-jacketed lines with MLI installed outside the annulus area could be used for space orbiting transfer systems. MLI reduces the radiation heat transfer mechanism thus further reducing the heat leak to the cryogenic fluid.

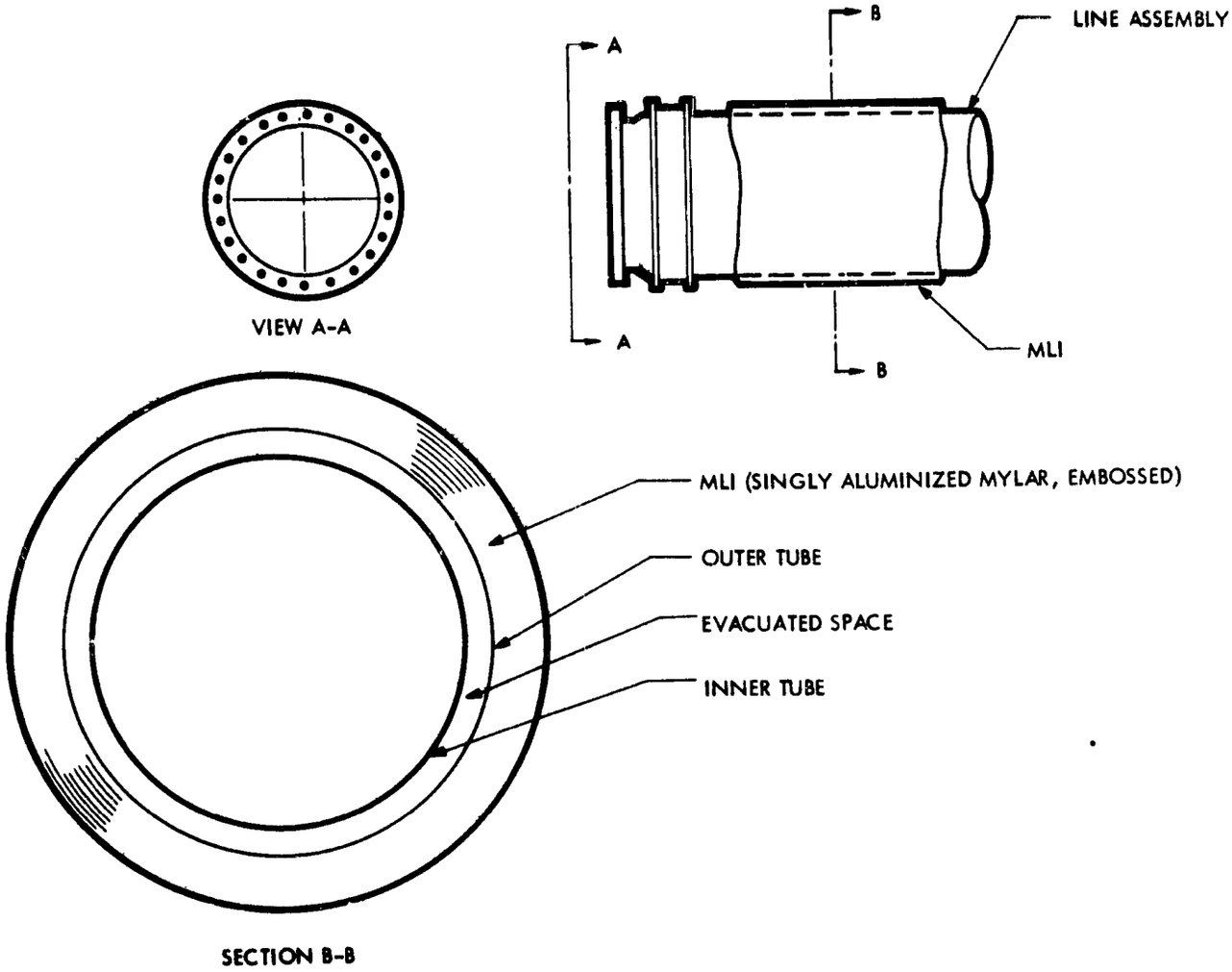


Figure 6.2.2.1-1. Vacuum-Jacketed Line Assembly Plus MLI

b. Performance Characteristics: No experience available for assessing characteristics.

c. System Limitation: System limitations are the same as those established for CIS study.

d. Design Problems: Design problems could include those discussed in Paragraph 6.2.1.2. Additional design problems would be associated with the MLI material, including methods of installation, outgassing of the MLI, attachment techniques, temperature limitations, and degradation of the optical characteristics of the MLI.

e. Design Verification: See Paragraph 6.2.1.2.

6.2.2.3 Thermal Performance

This composite design offers a heat transfer rate lower than that of a vacuum jacket only. The addition of SAME layers to the external surface of the jacket interposes major thermal resistance between the environment and the external jacket surface, which is especially effective in a space environment. The ground-hold maximum heat transfer rates are 30 Btu/hr-ft^2 for LH_2 lines and 45 Btu/hr-ft^2 for LOX lines, which are the same as those for vacuum-jacketed lines. However, the on-orbit heat transfer rate with MLI is approximately 0.5 Btu/hr-ft^2 for both the LH_2 and LOX lines. A more detailed analysis of thermal performance is presented in Paragraph 7.3.2.2

6.2.2.4 Structural Performance

The structural performance of this insulation system is identical to that given in Paragraph 6.2.1.4. In addition, this system contains additional insulation (MLI), over the outer jacket, which must function adequately under the loadings of pressure, temperature, and vibration. Of structural importance is the method of attaching the MLI to the outer jacket so that it does not tear or crush when subjected to the aforementioned loadings.

6.2.2.5 Materials and Processes

The vacuum-jacketed line plus aluminized Mylar was the insulation system proposed for the CIS study. The study did not include verification of the concept; therefore, the Materials and Processes group developed no procedures or techniques other than those described in Paragraph 6.2.1.5.

6.2.2.6 Manufacturing

No manufacturing information is available.

6.2.2.7 Quality Assurance

The proposed insulation system shown in Figure 6.2.2.1-1 never reached production status on the Saturn S-II program. However, the system is essentially "dual" insulation - a vacuum-jacketed line coupled with MLI. The vacuum-jacketed system was used extensively on S-II, and the quality assurance provisions are established in Paragraph 6.2.1.7. Although MLI was not used in production status on the S-II, an extensive research and development program was undertaken and key quality assurance operating procedures and techniques established. These provisions are outlined in Paragraph 6.1.10.7.

6.2.2.8 Repair and Maintenance

No information beyond that in Paragraph 6.2.1.8, is available.

6.2.2.9 Reliability

No Failure Mode Effects Analysis has been performed on this type insulation system.

6.2.2.10 Safety

This insulation system has not been fully developed. No detailed hazard analysis has been conducted, and no overall safety recommendations can be made. It is recommended that such an analysis be conducted on a detailed design when such a design is formulated.

Some components of the system, such as vacuum-jacketed lines, have been analyzed, and experience has been gained in fabrication, installation, and utilization. As a result, safety recommendations can be obtained from the other insulation systems that use these components. It is not expected that a different combination of components will materially alter the recommendations originally made for a single component, but an overall evaluation cannot be made without the aforementioned analysis.

For safety considerations associated with the basic vacuum-jacketed lines, see Paragraph 6.2.1.10; for MLI, see Paragraph 6.1.10.10.

6.2.2.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation systems relative cost. There are no data available on the hours required per foot length.

b. Schedule: The schedule flow times for this insulation system are not available.

c. Weight: The total as-installed weight is 7.04 pounds per foot of length.

d. Thermal Performance: The Q of this system is 30 Btu/hr-ft^2; ρK is 0.200 Btu/lb-hr-^{o}F-ft^4.

6.2.3 Glass Fiber Batting Encased in CRES Sheet

6.2.3.1 Description

This insulation system is used on the S-II liquid oxygen feed system (V7-531120). Heat transfer from a warm environment into the cryogenic fluid is reduced because of the low conductivity of the glass fiber insulating material. An influencing factor in the selection of materials for this system was the LOX-compatibility requirement.

Figure 6.2.3.1-1 illustrates glass fiber batting encased in CRES. Glass fiber batting is placed between formed inner and outer CRES facing sheets, which are then fused together with a continuous seam weld to completely encase the batting. The contour of the inner facing sheet is designed to conform to the outside contour of the area to be insulated. Lacing studs and venting provisions are added to the outer facing sheet to complete the assembly. The number, size, and configuration of assemblies required are dictated by the configuration of the area to be insulated.

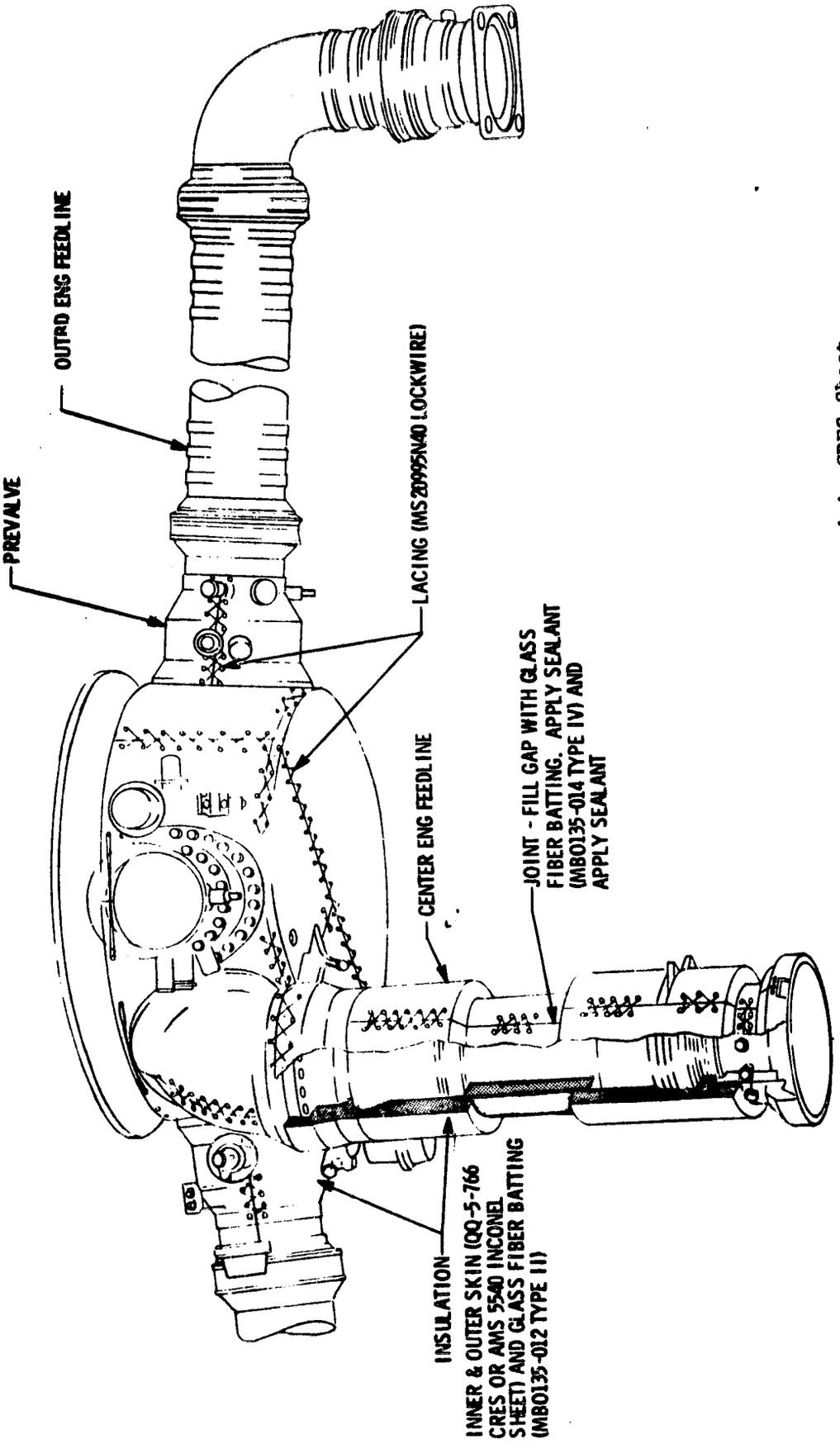


Figure 6.2.3.1-1. Glass Fiber Batting Encased in CRES Sheet

The insulation is installed by using the lacing studs for cross-lacing adjacent assemblies together with lockwire. The joints between adjacent assemblies and any exposed gaps are sealed using glass fiber batting, high silica fabric tape, and a brush-on elastomeric sealant. The completed installation is completely sealed to isolate the cryogenic surfaces from the warm environment.

6.2.3.2 Application

a. Utilization: The principal function of the glass batting/stainless steel system is to reduce the heat leak into the LOX feedlines. The stainless wrapping provides a LOX-compatible system and prevents moisture from contaminating the insulation.

b. Performance: The system has been used successfully on the S-II. The LOX pump inlet temperatures have been within the required engine start box.

c. System Limitations: The design of the system allows for both high and low temperatures. The high-temperature limits are the limit capability of the materials and the maximum internal pressure limits. Also, the system must be LOX-compatible and must not allow moisture to penetrate the insulation.

d. Design Problems: The system is an off-the-shelf design with modification to meet the specific design requirements of the S-II. No specific design problems have been experienced with this system.

e. Verification Tests: No specific verification tests were conducted on this system. Verification has been obtained, however, through flight evaluation data, which indicate the system has thermally protected the LOX feed system.

6.2.3.3 Thermal Performance

The thermal performance characteristics of this insulation system are given for a cryogenic propellant transfer line containing liquid oxygen. The external surface of the insulation is exposed to the induced environment of the S-II engine compartment. A detailed discussion of the thermal effects of insulated piping components on LOX recirculation system performance is presented in Paragraph 7.3.2.3.

The insulation requirements for the LOX sump, prevalves, and center engine feed line were determined by test and analysis. An effective thermal conductance of 0.3 Btu/hr-ft^2, selected for design purposes, reduces the prevalve body temperature adjacent to the LOX to approximately the temperature of nearby components of the outboard engine feed lines. Glass fiber batting has a thermal conductivity of 0.3 Btu-in/hr-^{o}F-ft^2 at room temperature. Therefore, a minimum thickness of 1 inch is required. At ambient temperatures, the heat flux to LOX is approximately 100 Btu/hr-ft^2. During thrust chamber chill, the heat flux is reduced to approximately 50 Btu/hr-ft^2.

6.2.3.4 Structural Performance

Critical loading on the insulation system, as used on the S-II, results from dynamic loading. Maximum stresses are developed in the CRES sheets and lacing wire during longitudinal vibration. Since the insulation is of lightweight construction, these stresses are minimal.

6.2.3.5 Materials and Processes

a. Materials:

1. Metal Sheet: Corrosion-resistant steel foil sheet, Federal Specification Q Q-S-766, or Inconel foil sheet, Aerospace Material Specification AMS 5540.

2. Batting: glass fiber, (MB0135-012 Type II).

3. Tape: high-silica fabric, (MB0135-014 Type IV).

4. Sealant: elastomeric fluorocarbon, room-temperature curing coating for cryogenic application (MB0120-043).

b. Processes: The insulation is fabricated and installed in accordance with the requirements of MA0605-017. Sealant processing is specified on the engineering drawing.

1. Material Storage and Handling: All materials are stored and handled in accordance with the requirements of their applicable material specification. Special handling precautions, to ensure maintenance of LOX compatibility, are stated in MA0605-017.

2. Batting/Metal Sheet Blanket Fabrication: As indicated in Paragraph 6.2.3.1, this insulation system requires fabrication of precontoured composites of glass batting and metal sheet.

(a) The foil facing sheets, textured by cross-corrugation to aid forming operations, are formed to the contour specified by the applicable engineering drawing. Lubricants or tool release agents may not be used in the forming process.

(b) Lacing studs, as required by the engineering drawing, are installed by continuous seam welding to the outer facing of the insulation blanket in accordance with MA0107-002.

(c) Venting provisions are incorporated in the outside steel foil skin of each insulation assembly. A vent hole is placed in the foil in such a position to prevent water drainage into the batting. The holse is covered with a welded-on envelope to prevent drainage in flow.

(d) The glass batting, one half inch in nominal thickness, is cut in flat patterns to fit within the formed foil facings. The batting fibers must not extend into edge and cut out areas that will be welded subsequently.

(e) The inner and outer foil facings at edges and cut-outs are joined by continuous-resistance seam welds in accordance with MA0107-002. The weld nugget width must be at least three times the joint thickness.

3. Installation of Blankets: The metal blanket surfaces are cleaned with trichloroethane, applied to the structure, and secured in place by cross-lacing with lockwire. When installed, the detail blankets must conform to the outside contour of the structure, and the maximum gap between the installed details in 0.25 inch. The maximum allowable gap between the insulation blanket and the structure is 0.06 inch.

4. Sealing: Joints and gaps in the installed insulation blankets are sealed with glass batting, tape, and elastomeric sealant.

(a) The surfaces to be sealed are cleaned in accordance with MA0110-010.

(b) All gaps and joints are filled with glass batting material.

(c) The LOX-compatible elastomeric sealant is applied to the glass batting material.

(d) High-silica tape is applied to the joint area to secure the coated glass batting.

(e) Four brush coats of the elastomeric sealant are applied to the tape surfaces, allowing an air dry of 30 to 40 minutes between coats and a total cure of the last coat of 72 hours to cryogenic exposure.

6.2.3.6 Manufacturing

a. Description: The LOX feed system insulation is made of an inner and an outer Inconel skin about 0.004 inch thick. In between the cavity created by the shape of the skins is the glass batting insulation. Skins are formed over dies in a hydropress, then hand-worked with special cutters to proper dimensions. Vent hole cover and stud assemblies are dimensionally located on the outer skin surface. The skin is cut for acceptance of studs and vent assembly and carefully hand-worked for spot-welding operation. Batting retainer strips, to prevent batting from contaminating final seam weld, are dimensionally located and spot-welded. All loose ends of batting are removed to prevent imperfect seam weld on final close-out. Inner and outer skins are prefitted and trimmed to match in preparation for final weld operation. After being welded, subassemblies are

handfitted to a master assembly tool by manually fitting each subassembly and hand-lacing with wire through stud shoulders. Assemblies are removed, hand-cleaned, and packaged in a shipping container. The Fabrication and Installation sequence is shown in Figure 6.2.3.6-1.

b. Tooling and Equipment: The tooling requirements consist of hydropress dies, and master facility tools. Equipment items required are special hard drill, tack welder , spot welder, special hammer, seam welder, shipping container, special cutters, and blunt nose pliers.

c. Problems: No problems

6.2.3.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0606-017):

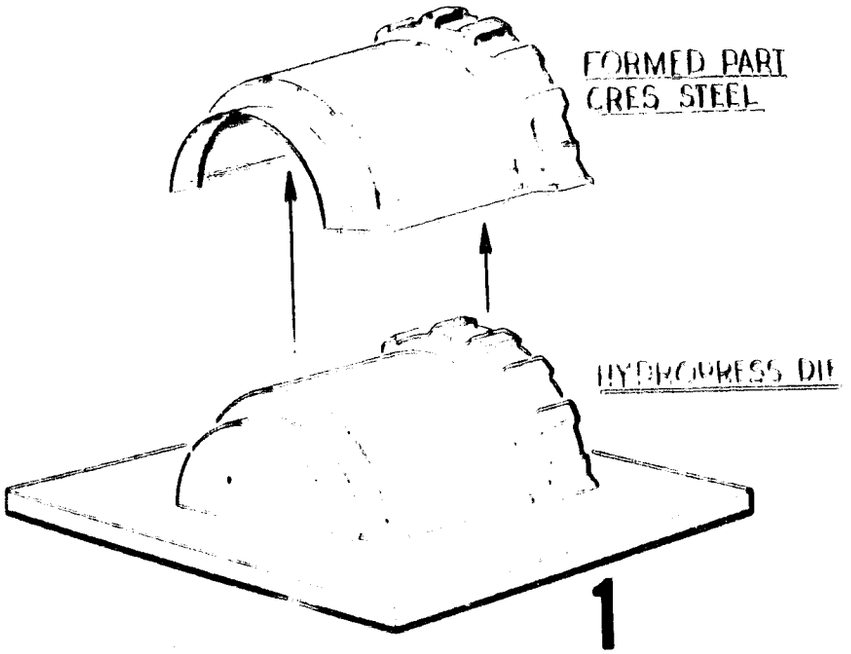
1. Cleaning: Because of the requirement that the insulation system be LOX-compatible, quality control emphasis was placed on cleaning, packaging, and handling procedures. All formed CRES parts were cleaned with inhibited instrument grade trichloroethane and packaged in sealed polyethylene envelopes until final assembly on the stage. Fiber batting (MB0135-012 Type II) also was stored in sealed polyethylene envelopes prior to use in production.

2. Welding: Resistance seam weld operations on the CRES foil were inspected to the requirements of MA0107-002, Class C welds.

3. Fit Check: Completed insulation details were installed on a master facilities checkout fixture to verify proper fit and location of parting lines. It was verified the maximum gap between the installed details was 0.25 inch and the maximum gap between the insulation detail and the component surface was 0.06 inch, except where bridging of bolt heads and flanges was required.

4. Visual Inspection: Completed insulation details were inspected to ensure that there were no holes or tears other than the designed vent holes in the foil facings and that there were no weld discontinuities in the seam welds.

c. Quality Verification of Final Assembly (Figure 6.2.3.1-1): Final acceptance was limited to visual inspection for proper fit as specified in Paragraph 6.2.3.7-b-3. In addition it was verified that all joints were properly taped with high silica fabric tape (MB0135-014, Type IV), and properly sealed with sealant (MB0120-043).



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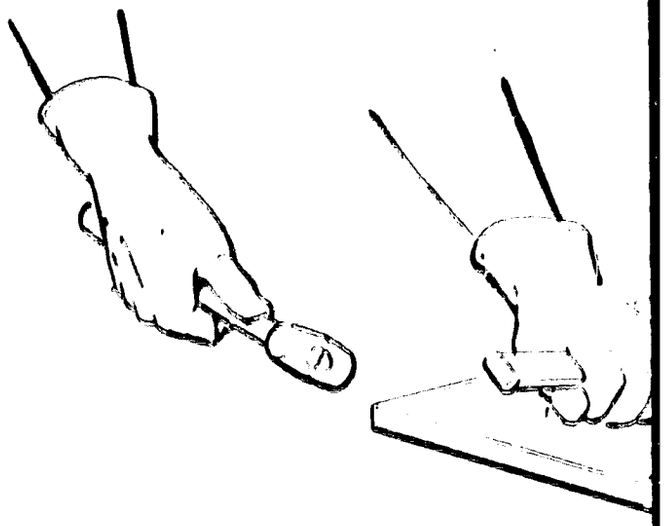

FINAL

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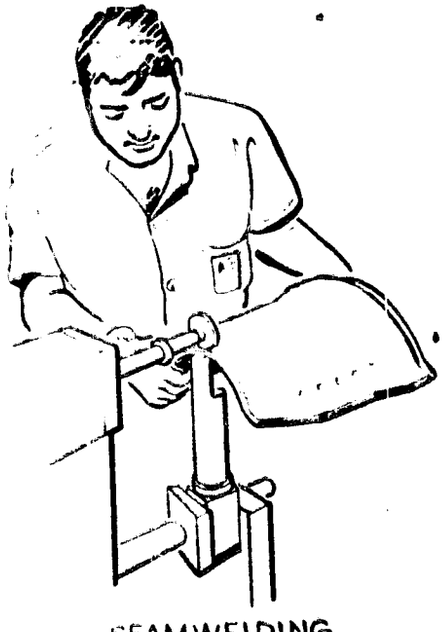


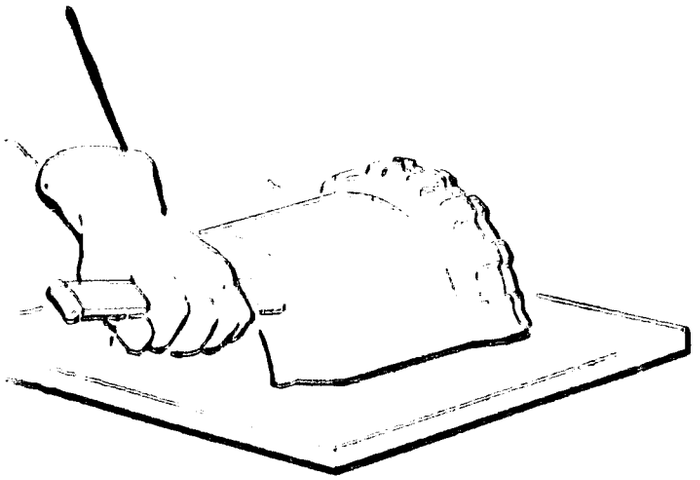
SEAMWELDING

5

SPOTWELDING
FINAL CLOSE DOT AND
TRIM

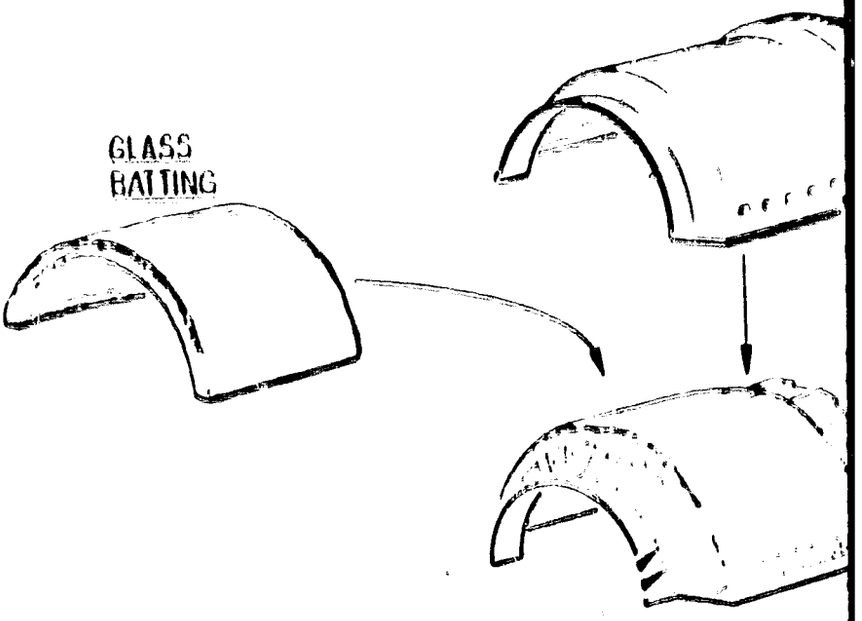
6

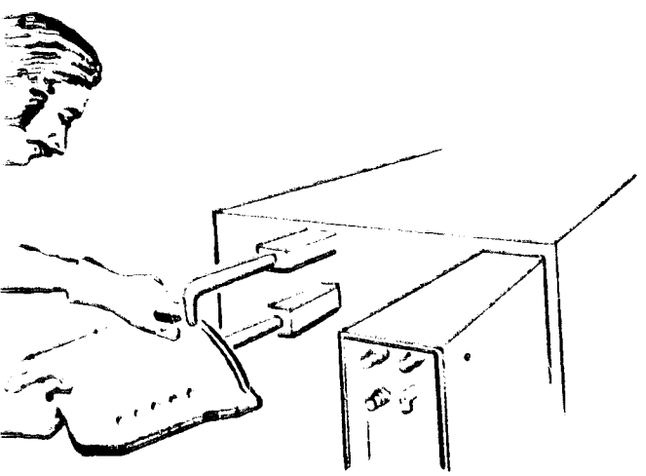
FOLDOUT FRAME



FINAL HAND-FORMING

2





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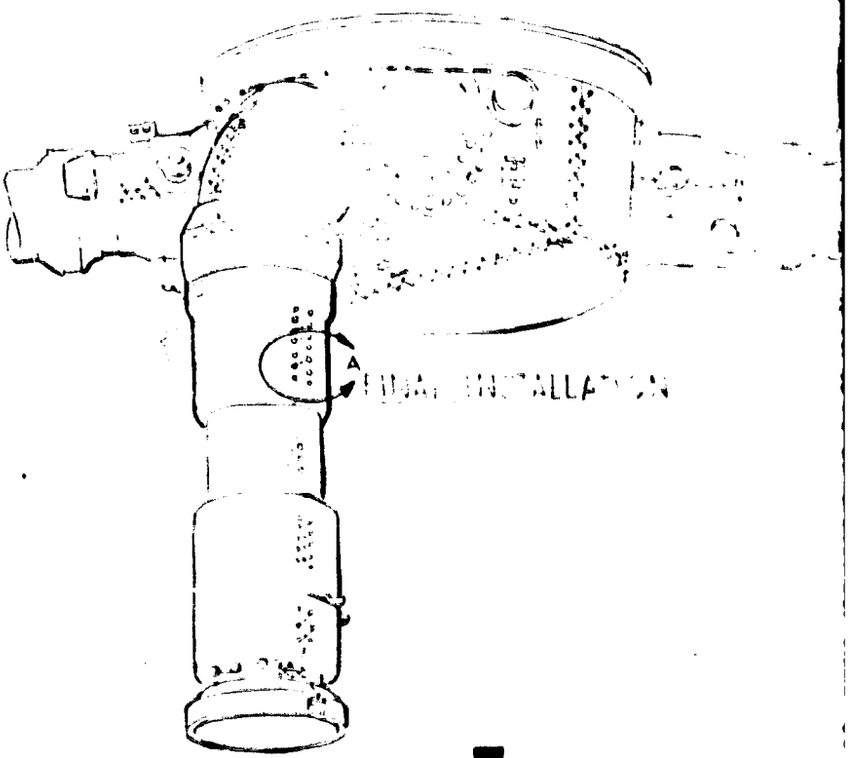

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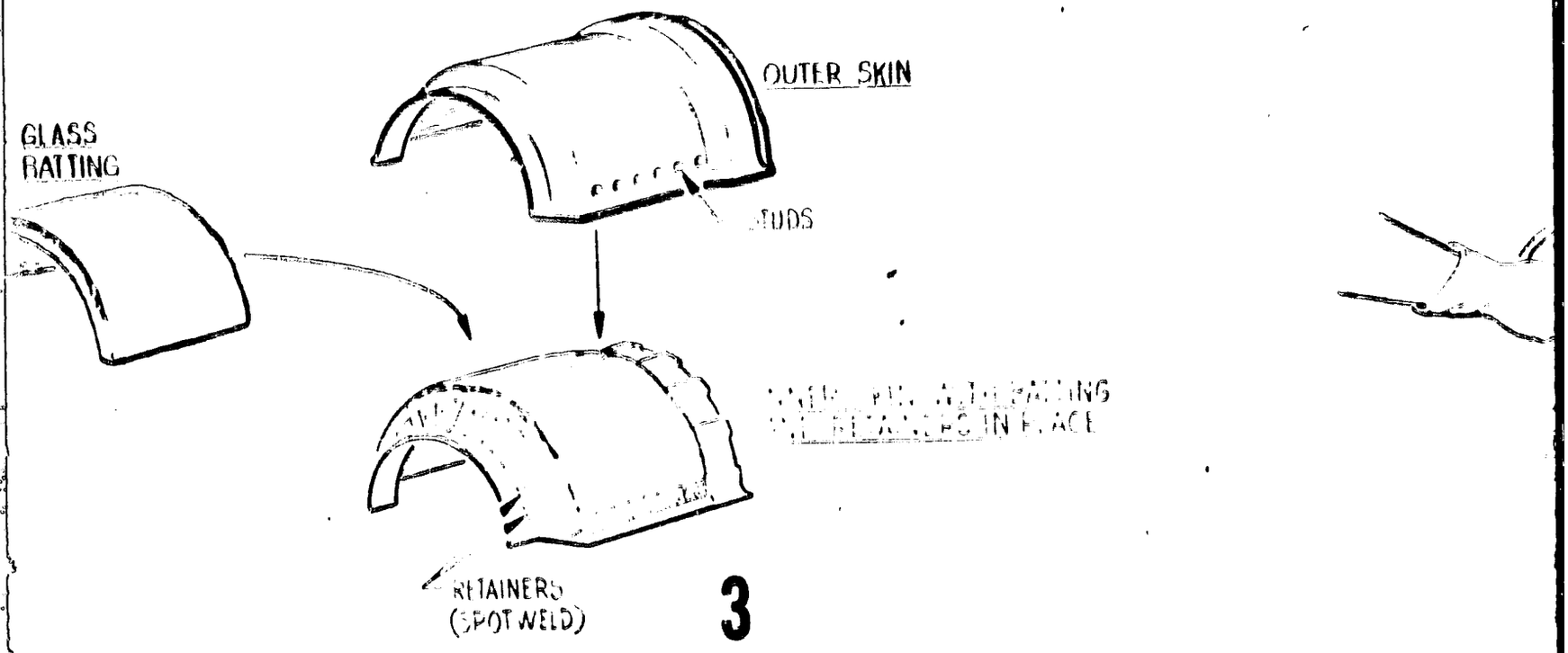
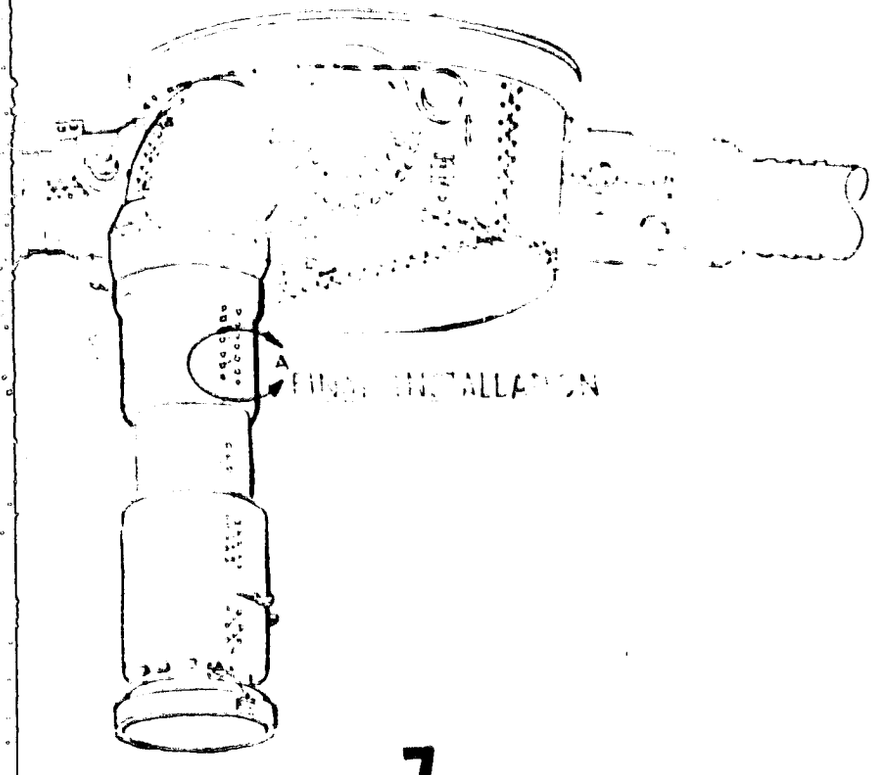
FOLDOUT FRAME 2





DETAIL A

Figure 6.2.3.6-1. Gl

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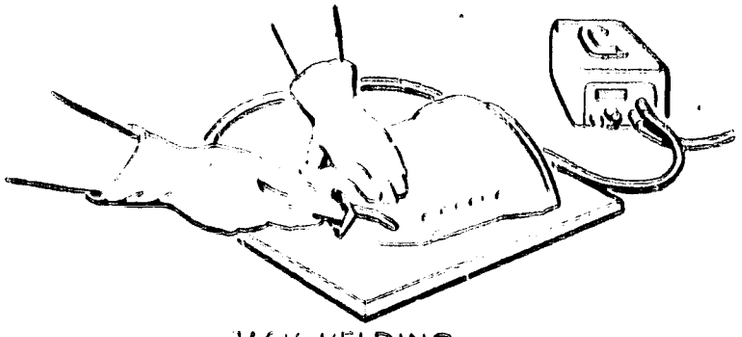


TACK WELDING

4

Figure 6.2.3.6-1. Glass Fiber Batting Enclosed in CRES Sheet

FOLDOUT FRAME 4

6.2.3.8 Repair and Maintenance

a. In-process rework for holes or tears that occur during fabrication of the metal foil facings is authorized by MA0605-017. Repairs are made by seam welding a patch over the damaged area. Any other rework or repair requires Material Review Board approval.

b. No special maintenance procedures, other than good housekeeping practice, is required for this insulation system.

6.3.2.9 Reliability

There was no detailed failure mode effect analysis formulated because of the absence of any obvious first-order failure modes. The mechanical lacing technique to join insulation segments was considered redundant and therefore offered no first-order modes of failure. The testing and flight history of the Saturn S-II reveals no failure of this type of insulation.

6.2.3.10 Safety

a. Fabrication and Installation: During fabrication and installation of components of this insulation system, care must be exercised to ensure that no contaminating material is introduced that is not LOX-compatible. Clean white nylon gloves must be worn at all times by handling personnel. During storage, the components must be packaged and protected to prevent contamination or damage. Additional safety requirements are given in Paragraph 6.1.1.10.

b. Glass Fiber Insulation Use: After the installation of this insulation system, care must be exercised when working in the vicinity to prevent damage to the surface.

c. After cryogenic exposure, the insulation must be examined for damage, and if damage has occurred, repaired.

6.2.3.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. There are no data available on the hours required per square foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement — 6 weeks.

Subassembly — 8 weeks.

Installation — 1 week.

Checkout — data not available.

c. Weight: The total as-installed weight is 0.612 lb/ft^2.

1. CRES sheet, inner, 0.004 inch thick 0.1647 lb/ft^2
2. Glass batting, 0.5 inch thick, 6 lb/ft^3 .2500 lb/ft^2
3. CRES sheet, outer, 0.006 inch thick 0.2471 lb/ft^2

d. Thermal Performance: The Q of this system is 150 $Btu/hr-ft^2$; ρK is 0.389 Btu/lb-hr-°F-ft4.

6.2.4 Glass Fiber Batting — Tape-Wrapped

6.2.4.1 Description

This insulation system is used on the S-II liquid oxygen feed system (V7-532001 and V7-531120). Heat transfer from a warm environment to the cryogenic fluid is reduced because of the low conductivity of the glass fiber insulating material. An influencing factor in the selection of materials for this system was the LOX-compatibility requirment.

The concept for tape-wrapped glass fiber batting insulation is shown in Figures 6.2.4.1-1 through 6.2.4.1-4. Insulation details are cut from glass fiber batting, formed to approximate the contour of the component or area to be insulated, and coated with an elastomeric sealant. After the coating has dried, details are snugged into intimate contact with the surface to be insulated with a high-silica fabric tape. The tape, which is wrapped in a random pattern, need not cover 100 percent of the insulation surface. The exposed surface of the tape is then brush-coated with the elastomeric sealant. The sealant is used to protect the insulation details from moisture absorption and to seal the area insulated against warm environmental gases.

6.2.4.2 Application

a. Utilization: This insulation system is very easy to install and allows forming over complex contours. The materials are used in many applications such as steam lines, oil lines, tanks, valves, and refrigerators. It has good high- and low-temperature properties as well as low thermal conductivity.

b. Performance: When used on the S-II, this system maintained the LOX pump inlet temperature within the start box requirements.

c. Limitations: The limitations are the same as those defined in Paragraph 6.2.3.2.

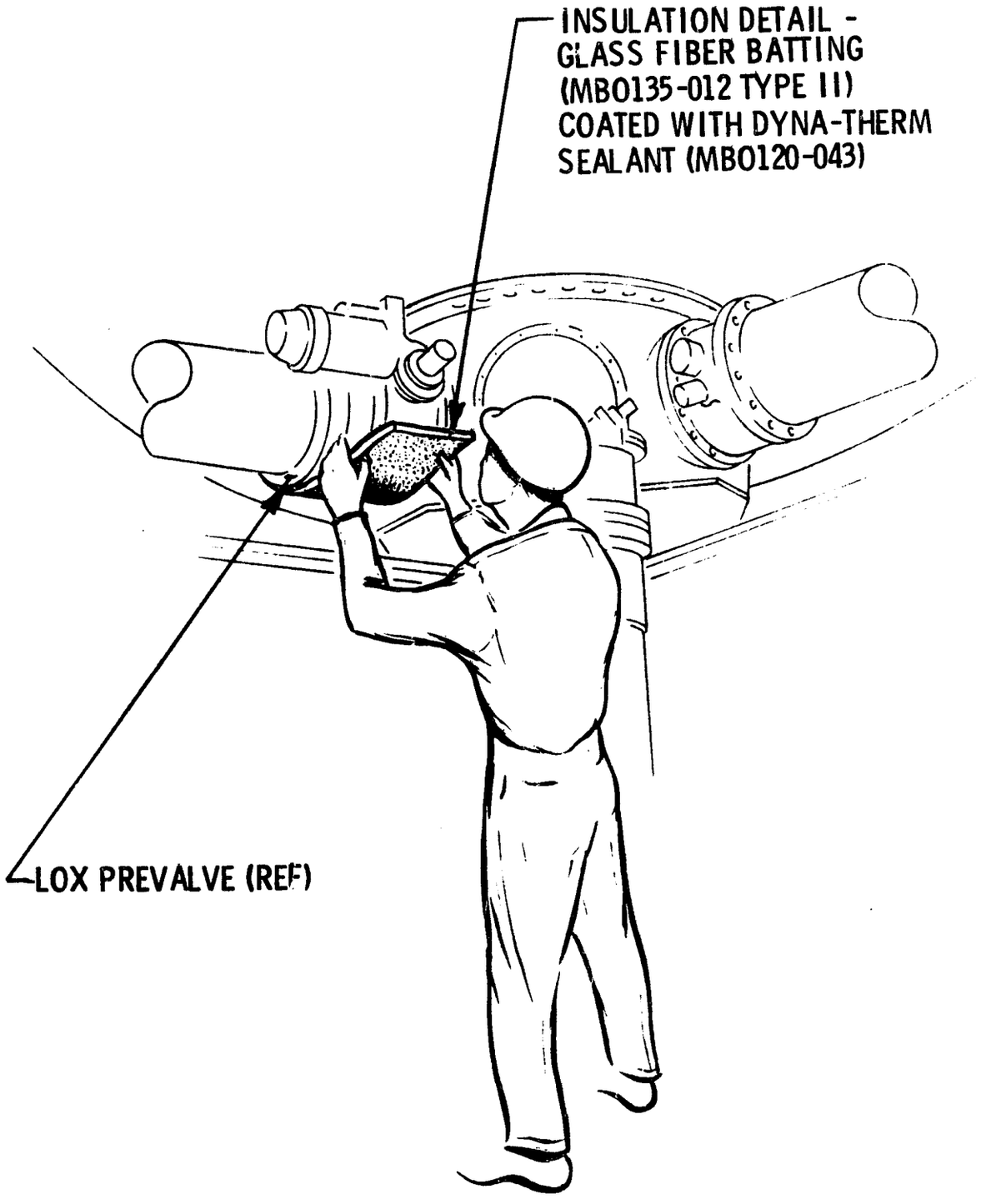


Figure 6.2.4.1-1. LOX Prevalve Insulation Detail

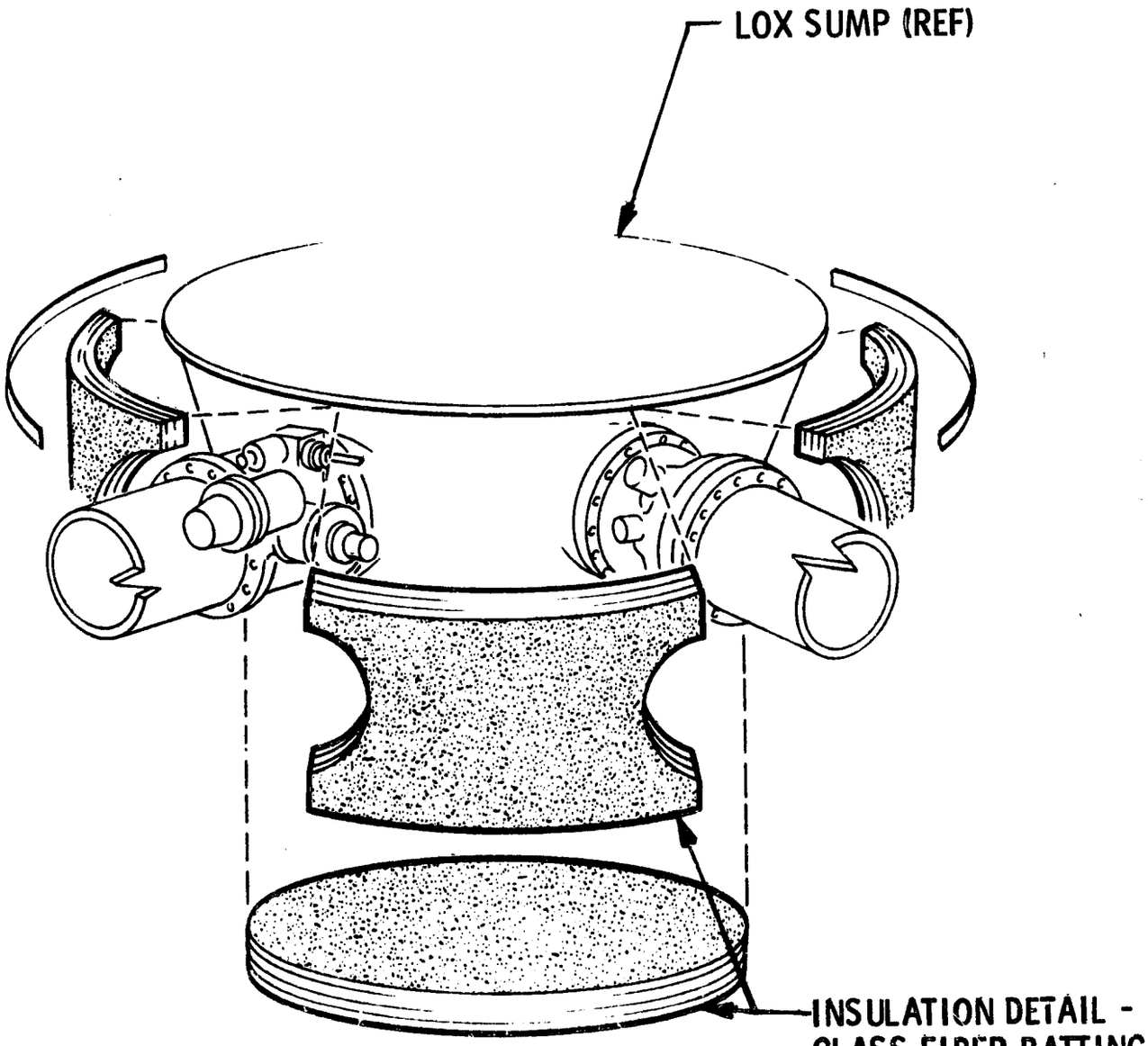


Figure 6.2.4.1-2. LOX Sump Insulation Detail

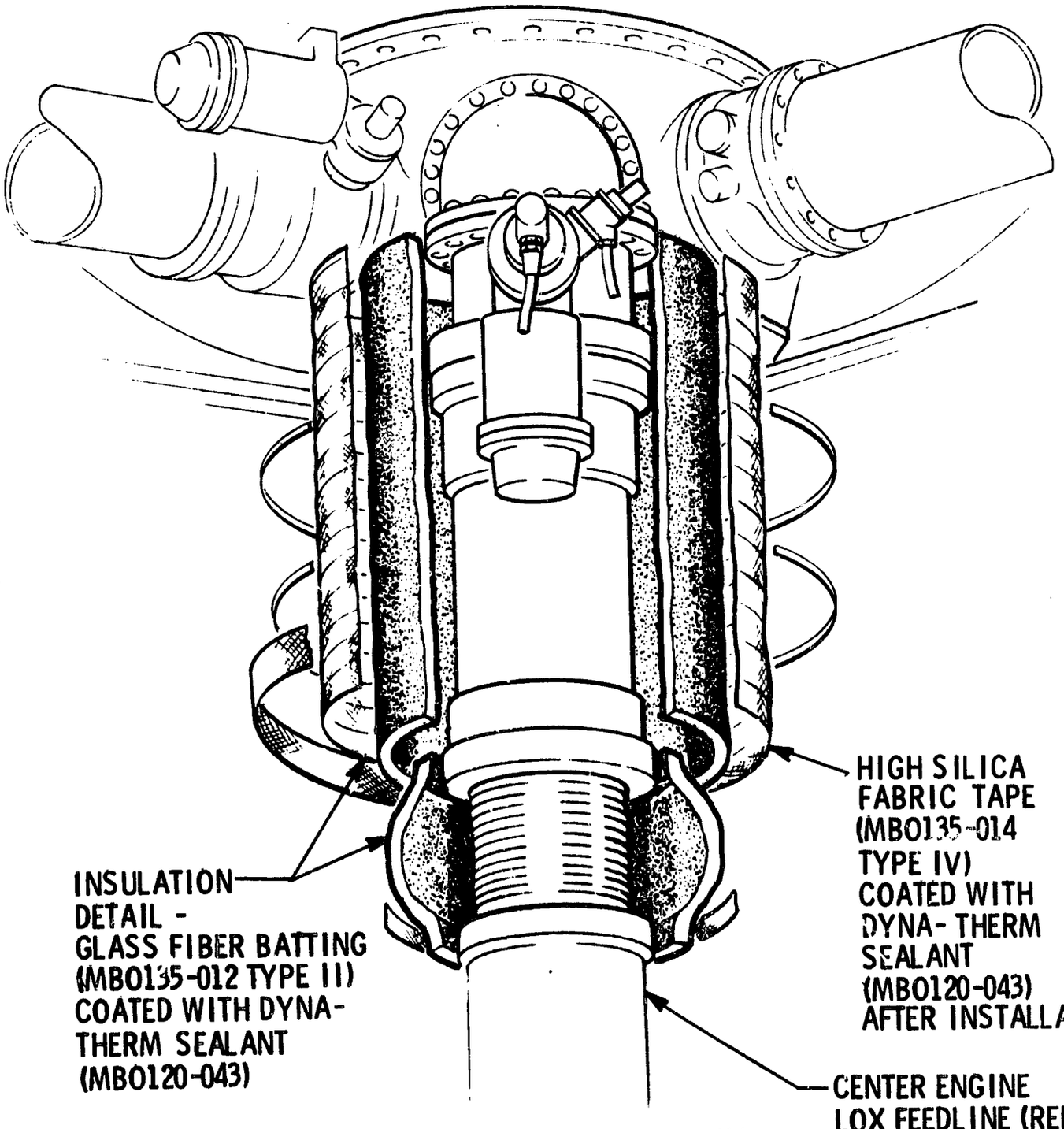


Figure 6.2.4.1-3. LOX Center Feedline

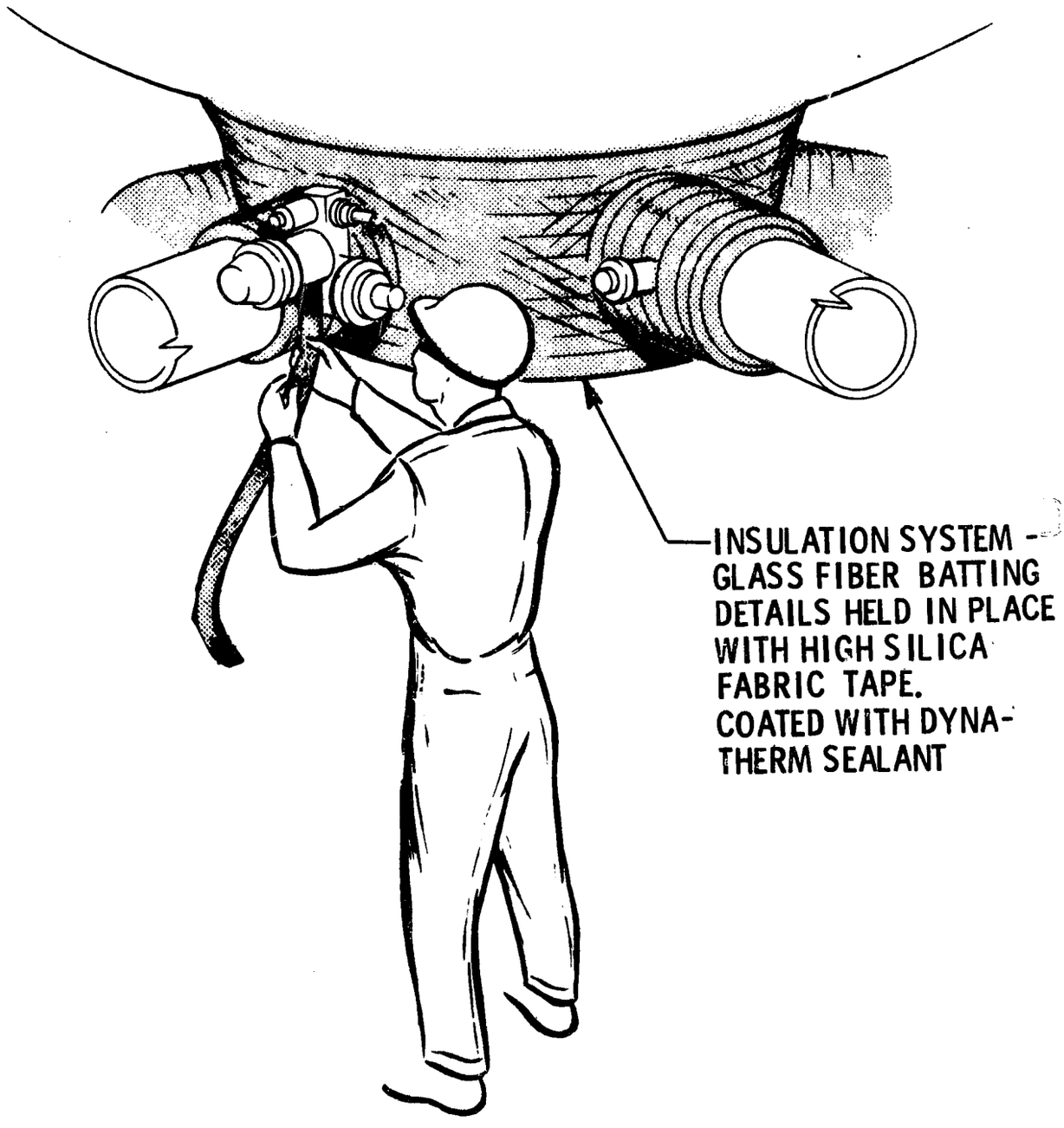


Figure 6.2.4.1-4. LOX Sump

d. Design Problems: The major design problem is in sealing against moisture. This problem was minimized when the design described in Paragraph 6.2.3.1 was implemented.

e. Verification Tests: No specific verification tests were conducted on this system. Verification was obtained from successful performance of the flight vehicles.

6.2.4.3 Thermal Performance

The thermal performance characteristics of this insulation system are identical to those of the system employing glass fiber in CRES sheet, (Paragraphs 6.2.3.3 and 7.3.2.3). The thermal conductivity is 0.3 Btu-in/hr-°F-ft^2 at room temperature, and the ambient temperature heat flux is approximately 100 Btu/hr, based on 300 F.

6.2.4.4 Structural Performance

Critical loading on the insulation system, as used on the S-II, results from dynamic loading. However, since the entire insulation system is of lightweight construction, these stresses are negligible.

6.2.4.5 Materials and Processes

a. Materials:

1. Batting: glass fiber (MB0135-012 Type II).

2. Tape: high-silica fabric (MB0135-014 Type IV).

3. Sealant: elastomeric fluorocarbon, room-temperature curing coating for cryogenic application (MB0120-043).

b. Processes: The insulation system is installed in accordance with MA0605-016.

1. Material Storage and Handling: All materials are stored and handled in accordance with their applicable material specification. Special handling precautions, to ensure maintenance of LOX-compatibility requirements, are stated in MA0605-016.

2. Environmental Control: Mixing and application of sealant material and assembly of insulation details are done in an area maintained at 60 to 90 F and a maximum relative humidity of 70 percent.

3. Cleaning: To ensure that LOX-compatibility requirements are met, cleaning procedures for insulating surfaces, mixing equipment, and fibrous materials are specified in MA0605-016.

4. Sealant Preparation: Single-component elastomeric sealant is mixed by stirring to a uniform consistency. The material may not be mixed by shaking techniques. When two-component sealant is used, it is combined in the weight ratio specified by the manufacturer. The two-component sealant may be thinned for the spraying application by adding 25 to 30 parts by weight of reagent grade MEK to 100 parts by weight of the mixed sealant.

5. Fabrication of Insulation Details: Flat patterns of the area or component to be insulated are cut from glass fiber batting sheet stock. The detail must be trimmed at least one inch oversize to allow for trim on final assembly. The batting detail is formed over a male fixture of contour approximating that of the component to be insulated. The batting may be held in position with masking tape provided it contacts the batting outside the final trim area.

6. Sealing of Insulation Faces: Both faces of the batting detail are sealed with sealant applied with conventional spray equipment powered with dry air or nitrogen. Four box coats are applied to the outer batting surface, allowing 10 to 15 minutes between coats and curing the fourth coat at 200 ± 10 F for 30 to 40 minutes. The coated batting is removed from the form and spread open on a clean, flat surface. The sealant is then applied to the inner surface in the same manner as described above. The detail is cured at least an additional 12 hours at 200 ± 10 F. The coated batting is then trimmed with scissors to fit the area to be insulated. The peripherals of insulation are then stitched together with stainless steel staples.

7. Sealing of Insulation Edges: The edges of the insulation details are sealed by brush-coating with sealant. Nine brush coats are applied, allowing a 15- to 20-minute air dry followed by a partial cure at 200 ± 10 F for 30 to 40 minutes between every three coats. An additional 12-hour cure at 200 ± 10 F of the edge-sealed insulation detail is required.

8. Installation: The insulation details are lagged in place on the structure using LOX-compatible, high-silica tape. The tape is wrapped around the insulation details in a random pattern to snug them into intimate contact with the component being insulated. The insulation details on the base of the LOX sump housing are installed by using an aluminum locking plate, as detailed on the engineering drawing.

9. Sealing: Elastomeric sealant is applied to the exposed tape surfaces. A minimum of four brush coats of sealant are applied, allowing a 30-minute air dry between coats and a 72-hour air dry prior to exposure to cryogenic temperatures.

6.2.4.6 Manufacturing

a. Description: Saturn S-II LOX sump and engine feed line components are insulated using glass fiber batting wrapped with high-silica fabric tape and sealed with an elastomeric compound. Glass fiber battings are cut to size using flat-developed templates and scissors. The oversized batting material is then formed over a male mockup and held in place with masking tape. The masking tape is affixed to the batting outside the final trim areas. The batting is hand-sprayed with a sealant atomized with nitrogen, applying four coats and allowing a 15-minute dry between each coat. After each two coatings, the batting is oven-cured for 30 to 40 minutes at 200 F for 12 hours. After cure, the batting is removed from the mockup and forced open to a semiflat condition on a clean, flat surface. The sealant is sprayed on the inside surface, dried, and oven-cured. Insulation performed details are cut to size with scissors, being very careful not to cause delamination. The entire peripheries of the trimmed insulation are stitched together, coated, and oven-cured.

   The assemblies are installed on the LOX system components and carefully held in place. High-silica tape is then randomly wrapped over the battings; it need not necessarily cover 100 percent of the surface. Venting provisions for expulsion of entrapped air must be provided. Sealant is then applied in four brush coats and allowed to dry between each coat for 30 to 40 minutes. After the last coat, a cure of 72 hours is required before exposure to spacecraft operating conditions. The fabrication and installation sequence is shown in Figure 6.2.4.6-1.

b. Tooling and Equipment: Tooling consists of a male mockup to form and cure the glass batting insulation components. Equipment consists of scissors, container for the elastomeric sealant, oven, work table, paddles, and paint brushes.

6.2.4.7 Quality Assurance

a. Raw Material Control: The raw materials utilized in the tape-wrapped glass batting insulation system are essentially the same as those used in the CRES/glass batting system described in Paragraph 6.2.3.7. The only exception is that the CRES envelope is not employed in this insulation composite. Therefore, the quality assurance aspects of raw material control were as described in Paragraph 6.2.3.7-a.

b. Subassembly Process Control (MA0605-016): Fabrication and installation of the coated batting details was a cut-to-fit process. The manufacturing operation was accomplished on the vehicle at the Kennedy Space Center launch complex. In-process quality control was limited to verification of proper cleaning, complete sealant coverage, and proper cure times and temperatures.

c. Quality Verification of Final Assembly:

1. Process Verification Test Coupons: Samples of batting (MB0135-012, Type II) were sealed with sealant (MB0120-043) simultaneously with the preparation of the production details. The samples were subsequently submerged in distilled water for six hours to determine the level of moisture absorption. Maximum allowable water absorption was 5 percent.

2. Visual Inspection: Final acceptance was based on a visual inspection for proper fit, taping, and complete surface sealing.

6.2.4.8 Repair and Maintenance

No standard repair or maintenance procedures were developed.

6.2.4.9 Reliability

There was no detailed failure mode effect analysis formulated because of the absence of any obvious first-order failure modes. The multiple wrapping of tape plus the coating of sealant was considered redundant and therefore offered no first-order modes of failure. The testing and flight history of the Saturn S-II reveals no failure of this type of insulation.

6.2.4.10 Safety

a. Fabrication and Installation: During the fabrication and installation of components of this insulation system care must be exercised to ensure that no contaminating material is introduced that is not LOX-compatible. Clean white nylon gloves must be worn at all times by handling personnel. During storage, the components must be packaged and protected to prevent contamination or damage.

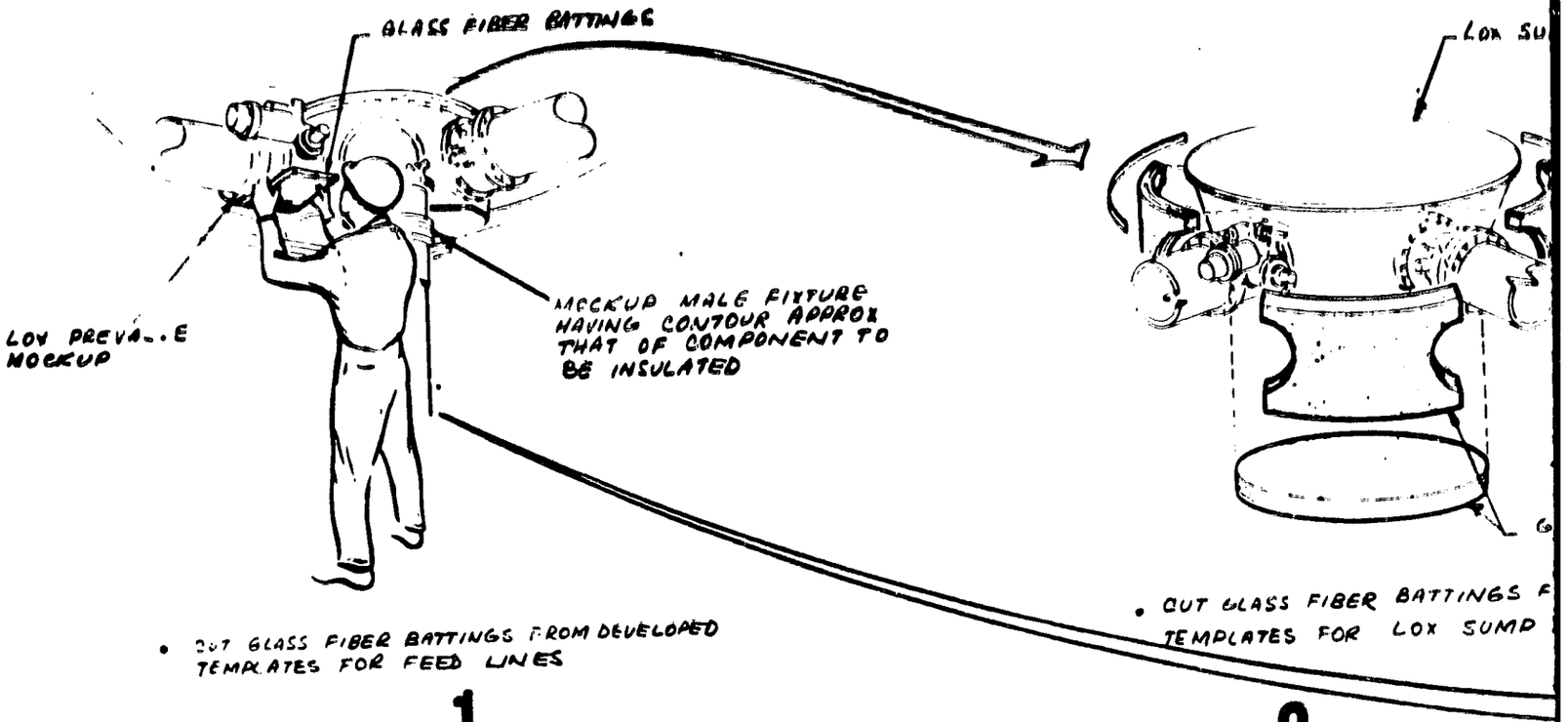
Additional safety requirements are given in Paragraph 6.1.1.10.

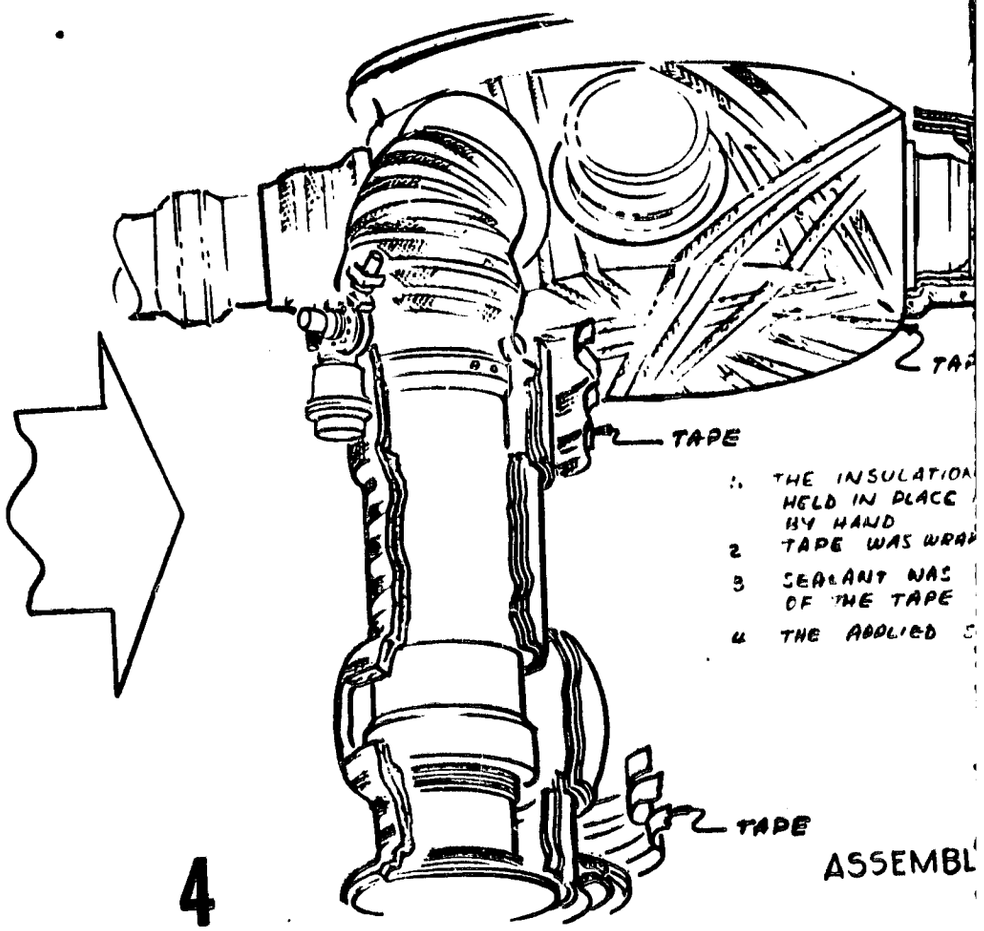
b. Glass Fiber Insulation Use: After the installation of this insulation system, care must be exercised when working in the vicinity to prevent damage to the surface.

After cryogenic exposure, the insulation must be examined for damage and, if damage has occurred, repaired.

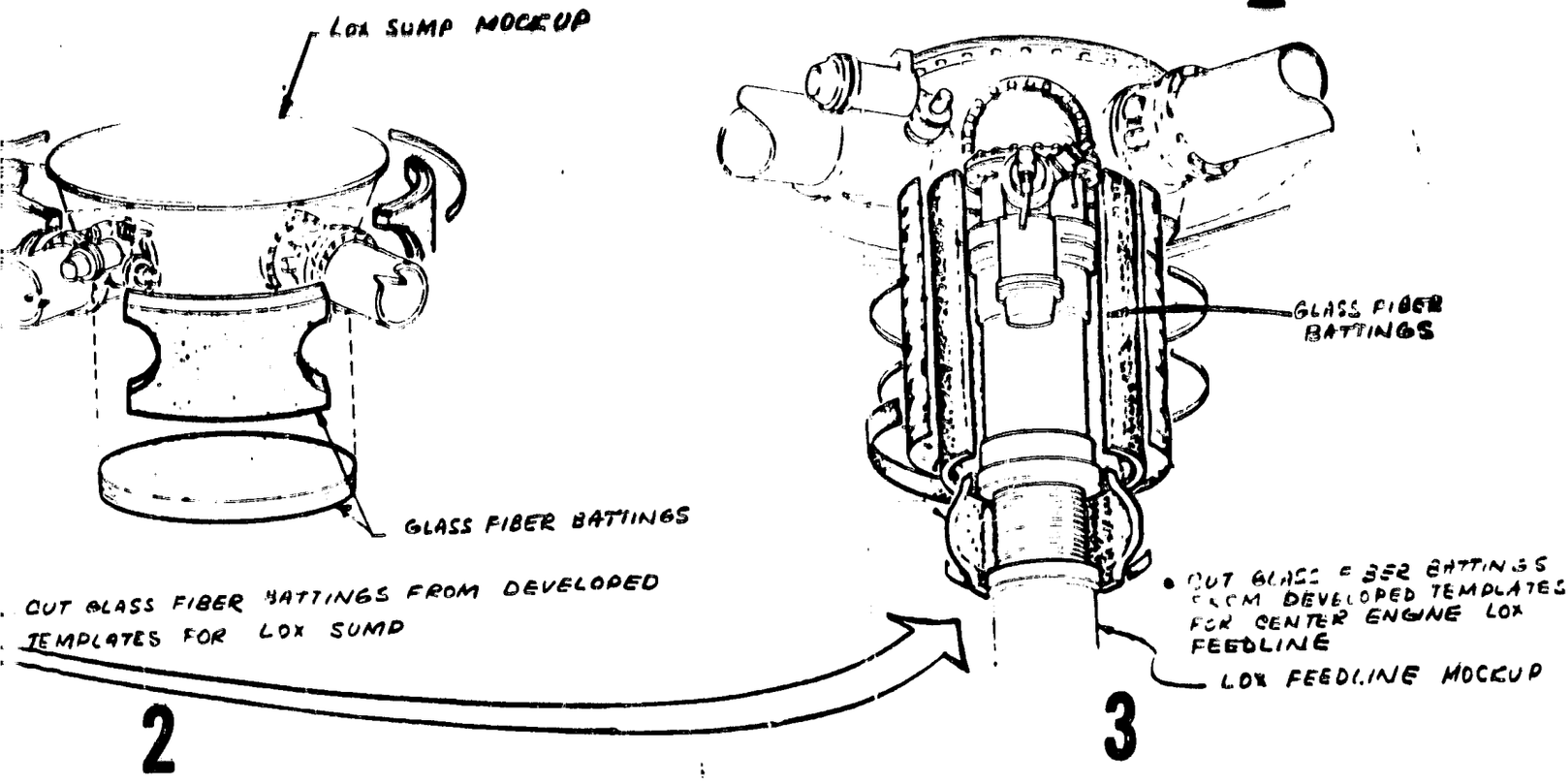
6.2.4.11 Design Effectiveness

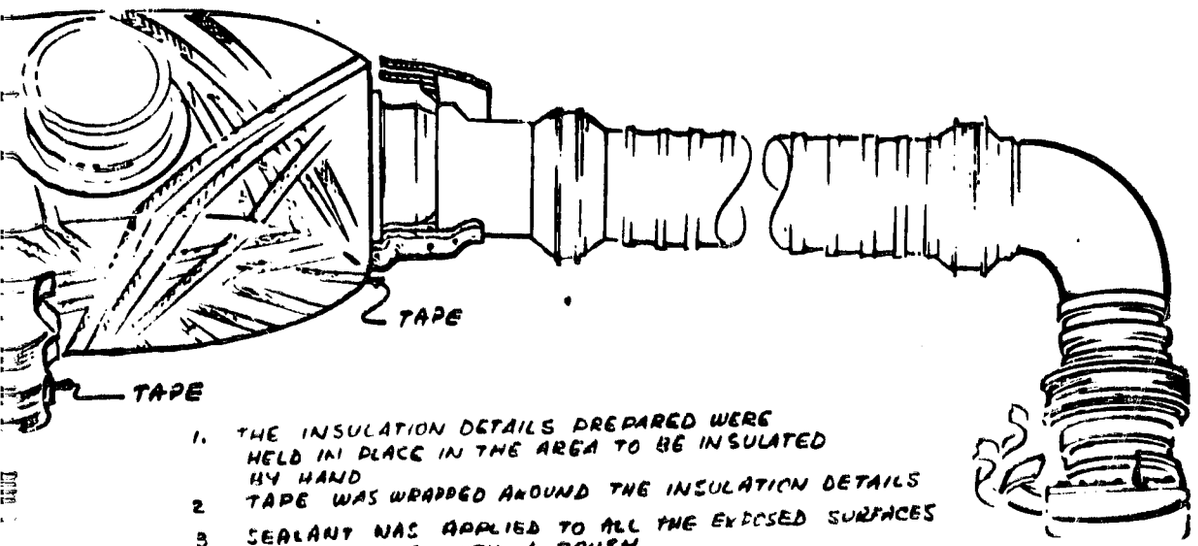
a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. No data are available on the hours required per square foot.





FOLDOUT FRAME





1. THE INSULATION DETAILS PREPARED WERE HELD IN PLACE IN THE AREA TO BE INSULATED BY HAND
2. TAPE WAS WRAPPED AROUND THE INSULATION DETAILS
3. SEALANT WAS APPLIED TO ALL THE EXPOSED SURFACES OF THE TAPE WITH A BRUSH
4. THE APPLIED SEALANT WAS CURED AT ROOM TEMPERATURE

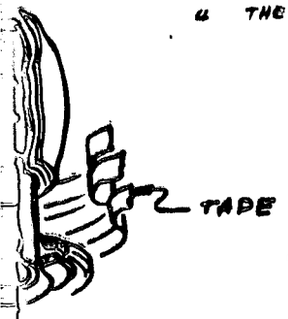


Figure 6.2.4.6-1. Glass Fiber Batting - Tape Wrapped

b. Schedule: The schedule flow times for this insulation system are not available.

c. Weight: The total as-installed weight is 0.708 lb/ft^2.

1. Dyna-therm, 2 coats (MB0120-043) — 0.048 lb/ft^2

2. Type IV tape (MB0135-014) — 0.160 lb/ft^2

3. Type II batting, 0.5 inch thick, 2 layers (MB0135-012) — 0.500 lb/ft^2

d. Thermal Performance: The Q of this system is 150 $Btu/hr-ft^2$; ρK is 0.464 $Btu/lb-hr-°F-ft^4$.

6.2.5 Pour Foam

6.2.5.1 Description

The pour foam system was originally used to insulate various sections and components of the LH_2 feed and recirculation systems on the S-II vehicles. It was replaced with the spray foam system described in Paragraph 6.2.6.1 in all areas where access permitted. The pour foam system was retained for insulating by encapsulation, the LH_2 feed line flanges located in the thrust cone area (V7-531325). Pour foam insulation is described in Paragraph 6.1.6.1.

A typical application of this insulation is shown in Figure 6.2.5.1-1. The LH_2 feed line flanges are first encapsulated in pour foam, and the foam is then covered with aluminum pressure-sensitive tape.

6.2.5.2 Application

a. Utilization: Pour foam is used on the LH_2 transfer line flanges to limit heat leak to the LH_2. Pour foam can be readily formed around components that are difficult to insulate efficiently by other means.

b. Performance Characteristics: There are no specific performance characteristics for this system. It functions as part of the total insulation system. Flight data have indicated satisfactory performance of the system.

c. System Limitations: This system was developed to meet S-II system requirements, as described in Section 5. Primary limitations are dictated by structural integrity in the complex configurations.

d. Design Problems: Design problems related to this system were as follows:

Problem	Solution
Accessibility to apply foam	No ready solution. Design of total insulation system must provide for producibility.

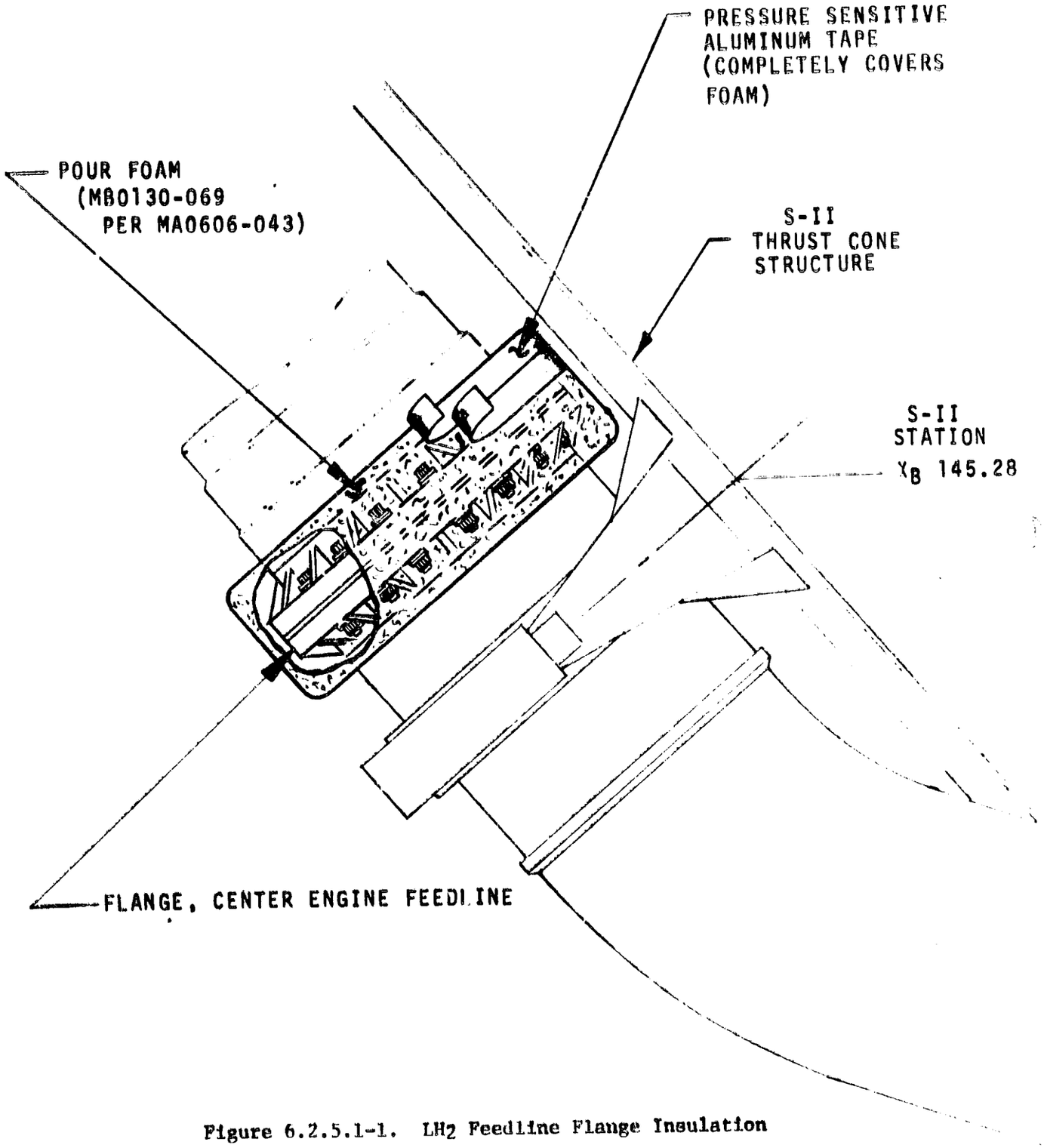


Figure 6.2.5.1-1. LH_2 Feedline Flange Insulation

Problem	Solution
Rind formation at foam/metal interface	Improved process conditions such as proper heat rejection and humidity control.
Metal corrosion under foam	Provide proper primer system. Eliminate processing contaminate residuals. Provide proper control for foam quality.
Poor adherence and porosity of foam	Match pour foam mechanical and physical properties to structural/ operational requirements.

e. Verification Tests: No specific tests were conducted for verification of this system for this application. The pour foam was developed and verified as part of the overall foam program. Data from flight tests provided verification of the system. No failures of the system in-flight have been indicated.

6.2.5.3 Thermal Performance

The thermal performance characteristics of pour foam insulation for cryogenic transfer lines are identical to those for spray-on foam, discussed in Paragraphs 6.2.6.3 and 7.3.2.6. A respresentative value of thermal conductivity is 0.06 Btu/hr-°F-ft^2, and the corresponding heat flux to LH_2 is 265 Btu/hr-ft^2 for 1-inch thickness and 500 FΔT.

6.2.5.4 Structural Performance

Significant factors affecting the strength of cryogenic transfer pour foam insulation systems are identical to those given for cryogenic storage spray foam insulation systems in Paragraph 6.1.4.4.

6.2.5.5 Materials and Processes

a. Materials:

1. Adhesive: polyurethane resin system (MB0120-024).

2. Primer: a modified polyester/isocyanate adhesive primer system (MB0120-042).

3. Foam: low-density rigid polyurethane foam-in-place material (MB0130-069).

b. Processes: The foam-in-place insulation system for liquid hydrogen components was processed in accordance with MA0606-043.

1. Working Area: The working area environment is maintained at a temperature of 65 to 90 F and relative humidity of 75 percent or less.

2. Mold: The forming mold around the feed lines are fabricated of cardboard. The inner surface of the mold is coated with Johnson Paile wax and then coated with Thalco 5006 release agent. An equivalent release system may be used if approved by Quality Assurance.

3. Primer Application: The primer components are thoroughly mixed in accordance with instructions of the manufacturer. The unused primer is discarded after eight hours. The primer is thinned to a brushing or spraying consistency by adding solvent consisting of 30 percent MEK and 70 percent toluene by weight. The primer is applied until a continuous dried film of 1/2 mil, maximum, is obtained. The primer must cure a minimum of 4 hours at room temperature (60 to 90 F) before the foam is applied

4. Foam Application: The foam mold is prepared for the application of foam and assembled into position on the detailed assembly. The assembled mold is sealed at all joints. The areas adjacent to the foaming operation should be protected from the excess foam extruded from the mold. The modl may be removed after a minimum of 4 hours' cure at a minimum temperature of 65 F.

5. Aluminum Foil Application: Aluminum pressure-sensitive tape is applied to the foam insulation, as required by the engineering drawing. Two layers of the aluminum tape are applied to the prepared foam surface, with overlaps of 0.75 ± 0.25 inch. The first layer is applied longitudinally and the second layer is wrapped circumferentially. Each layer is thoroughly rubbed into place to eliminate voids and wrinkles.

6.2.5.6 Manufacturing

a. Description: The pour foam application technique is described in Paragraphs 6.1.6.6 and 6.1.7.6, and in Figures 6.1.6.6-1 and 6.1.7.6-1.

6.2.5.7 Quality Assurance

Quality control provisions for pour foam insulation are contained in Paragraph 6.1.6.7.

6.2.5.8 Repair and Maintenance

a. Repair: Pour foam insulation may be repaired by in-process rework procedures or by methods approved by the Material Review Board.

   1. In-Process Repairs: MA0606-043 provides for in-process rework of the pour foam as follows:

      (a) Complete removal of foam to metal substrate

      (b) Partial removal of foam

b. Maintenance: No special maintenance procedures are required for the pour foam installation system.

6.2.5.9 Reliability

There was no detailed failure mode effects analysis formulated because of the absence of any obvious first-order failure modes.

6.2.5.10 Safety

For safety considerations of pour-foam, refer to Paragraph 6.1.6.10.

6.2.5.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation systems relative cost. No data are available on the hours required per square foot.

b. Schedule. The schedule flow times for this insulation system are as follows:

Procurement - 5 weeks.

Subassembly - 0.

Installation - 1 week.

Checkout - 0.

c. Weight: The total as-installed weight is 0.286 lb/ft^2.

1. MB0130-069 foam, 1.00 inch thick 0.250 lb/ft^2

2. Aluminum tape 0.036 lb/ft^2

d. Thermal Performance: The Q of this system is 80 Btu/hr ft^2; ρK is 0.060 Btu/lb/hr-°F-ft^4.

6.2.6 Spray-On Foam

6.2.6.1 Description

This spray foam system is used to insulate various sections and components of the LH_2 propellant feed and recirculation systems on the S-II. The LH_2 feed system transfers the cryogenic fuel from the propellant tank outlet to the J-2 engine inlet duct. The plumbing involved consists basically of vacuum-insulated lines attached to flanges and of components which are not vacuum insulated. These flanges and components are encapsulated in spray-on foam described in Paragraph 6.1.4.1.

A typical application of this insulation concept is shown in Figure 6.2.6.1-1. The LH_2 feed line elbow, which has one end welded into the LH_2 tank wall, the LH_2 shutoff prevalve, a spool piece, and associated hardware within the insulation envelope are encapsulated in spray foam. The insulation is then covered with a nylon fabric impregnated with a polyurethane adhesive (wet layup). This concept is also used on other portions of the LH_2 systems, such as recirculation pumps and valves and the main propellant tank fill and drain valve.

It must be noted that electrical harnesses and connectors in these insulated areas require special processing prior to encapsulation. For details of this insulation design, see V7-531300.

6.2.6.2 Application

a. Utilization: In this application, spray foaming provides a relatively simple method of insulating around complex contours. The principal limitation is accessibility for foaming and trimming operations.

b. Performance Characteristics: There are no specific performance characteristics that can be given for this system. It functions as part of the total insulation system. Data from flight tests have demonstrated acceptable performance of the system.

c. System Limitations: This system was developed to meet S-II system requirements, as described in Section 5. Primary limitations are dictated by structural integrity in the complex configurations.

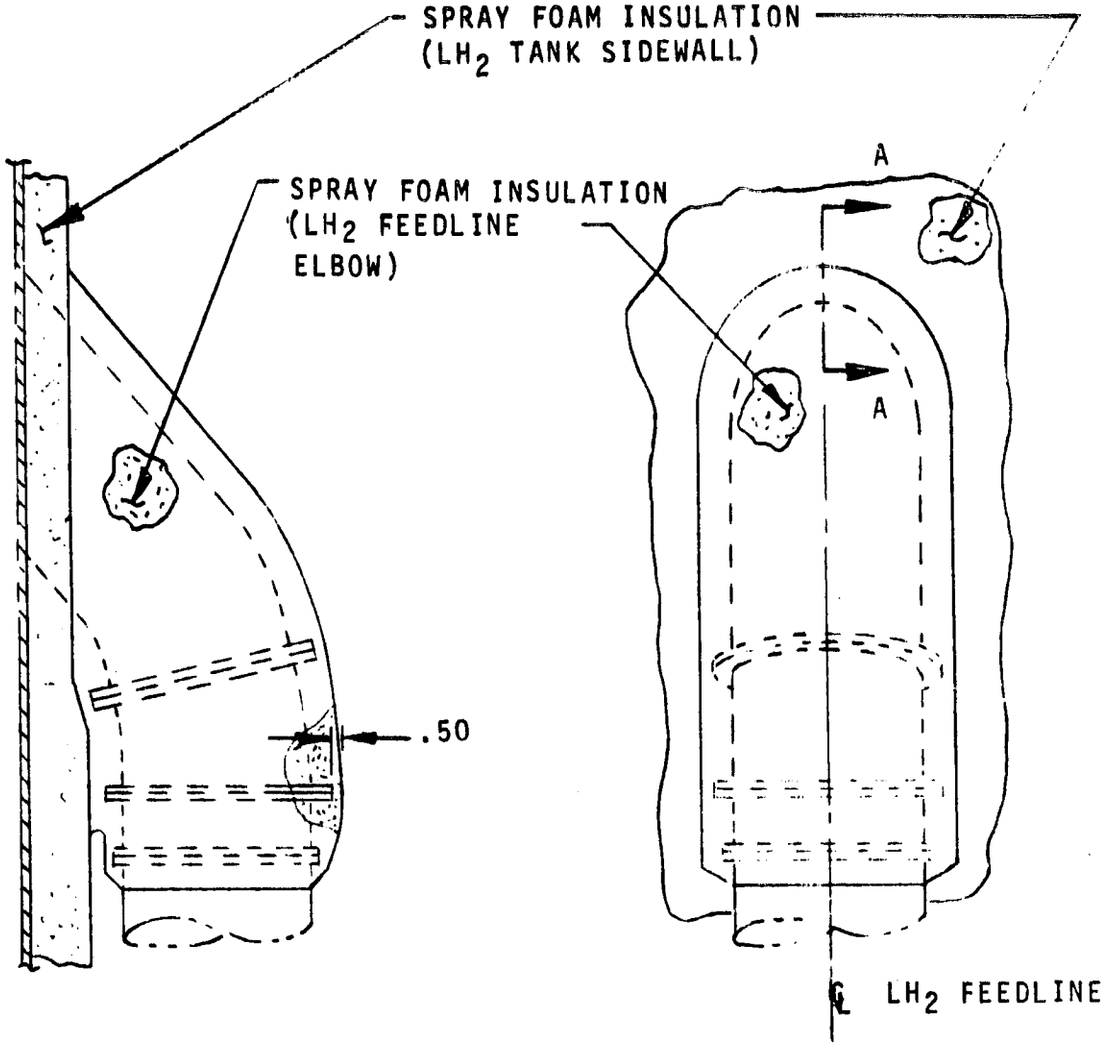
d. Design Problems: Design problems are summarized as follows:

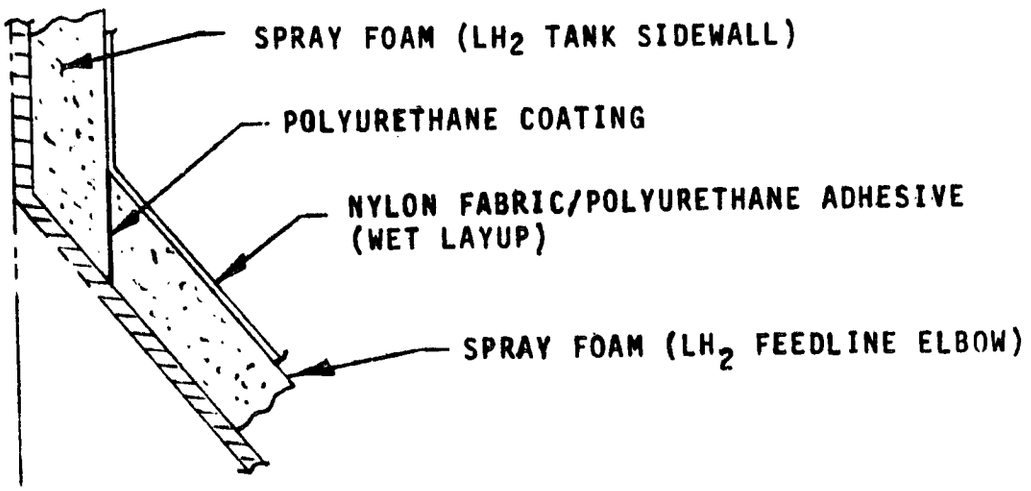
Problem	Solution
Rind formation around feed line elbws	Provide proper process conditions, such as reduced heat sink effects.
Voids in foam	Improve spray-foaming techniques, especially underneath feed line elbow cavity areas.

e. Verification Tests: The system was verified on a production feed line elbow specimen, with recirculation pump and associated hardware. The specimen was subjected to ten LH_2 fill-and-drain cycles. Inspection tests of the specimen were made to demonstrate adequacy, as described in Section 15.

6.2.6.3 Thermal Performance

The thermal performance characteristics of spray-on foam insulation are given for components of a cryogenic transfer line in which LH_2 is flowing. The line is exposed to ground-hold and launch environments, as defined in Sections 4.1.1 and 4.2, respectively. The overall heat transfer rates from the environment





SECTION A-A

Figure 6.2.6.1-1. Feedline Elbow Insulation

to the LH_2 flowing in the line are summarized below for different insulation thicknesses. Supporting analysis is presented in Paragraph 7.3.2.6.

Atmospheric air condenses on bare piping components that are chilled by LH_2. The resultant heat transfer rate due to cryo pumping is approximately 600 Btu/hr, which is unacceptably high. For a natural convection heating environment, the heat transfer rate to LH_2 is approximately 1000 Btu/hr-ft^2. This is high for most applications. When 1/2 inch of foam insulation is applied, the overall heat flux to LH_2 is reduced to 420 Btu/hr-ft^2. With 1 inch of foam insulation, the overall heat flux is reduced to 265 Btu/hr-ft^2. These computed results are summarized in Table 6.2.6.3-1. A foam thermal conductivity of 0.060 Btu/hr-°F-ft was assumed for the calculations.

For comparison, the heat transfer rate to LH_2 during orbit has been estimated. The no insulation heat flux of 360 Btu/hr-ft^2 represents absorbed solar radiation (Case 2). The assumed foam thermal conductivity of 0.002 Btu/hr-ft-°F represents the radiation and solid conduction limiting value. The orbital heat transfer rates to LH_2 for 1/2- and 1-inch foam thickness are 23.0 and 11.5 Btu/hr-ft^2, respectively.

6.2.6.4 Structural Performance

Significant factors affecting the strength of spray foam insulation systems for cryogenic transfer are identical to those given for cryogenic storage spray foam insulation systems in Paragraph 6.1.4.4.

6.2.6.5 Materials and Processes

a. Materials: See Paragraph 6.1.4.5.

b. Processes: The processes required to spray on the foam insulation shown in Figure 6.2.6.1-1 are the same as those in Paragraph 6.1.4.5. In addition, molds or manufacturing aids used for control of foam thickness or shape should be coated with a release agent approved by Quality Assurance. Caution: Do not use a silicone release system.

6.2.6.6 Manufacturing

a. Description: The spray-on foam technique is basically described in Paragraphs 6.1.4.6 and 6.1.5.6 and in Figures 6.1.4.6-1 and 6.1.5.6-1.

6.2.6.7 Quality Assurance

Quality control provisions for spray foam insulation are contained in Paragraph 6.1.4.7.

6.2.6.8 Repair and Maintenance

Repair and maintenance are defined in Paragraph 6.1.4.8.

Table 6.2.6.3.1. Thermal Performance Characteristics of Spray-On Foam Insulation Used on S-II Cryogenic Transfer Lines

Case	Description	Heat Transfer Rate ($Btu/hr-ft^2$)	
		Ground Hold	Orbit
1	No foam cryo pumping Air around LH_2 lines (a ground hold condition)	6000 (30 $lb/hr/ft^2$)	-
2	No foam Natural convection No cryo pumping GHe around LH_2 lines (a ground hold condition)	1000 (5 $lb/hr/ft^2$)	36.00
3	1/2-inch foam Natural convection No cryo pumping Air around LH_2 lines (a ground hold condition)	420	23.0
4	1-inch foam Natural convection No cryo pumping Air around LH_2 lines	265	11.5

Ground Hold Assumptions

Thermal conductivity of foam:	0.060 Btu/hr-ft-°F
Thermal conductance for convection:	2.0 $Btu/hr-ft^2-°F$
Overall temperature difference:	500 F

Orbit Assumptions

Thermal conductivity of foam:	0.002 Btu/hr-ft°F
Thermal conductance for radiation:	1.0 $Btu/hr-ft^2°F$

6.2.6.9 Reliability

The failure mode analysis is presented in Table 6.2.6.9-1

Table 6.2.6.9-1. FMEA – Spray-On Foam

Component	Failure Mode	Mission Effect
Spray-on foam insulation	Breaks off	Increased boil off, higher heat transfer rate, possible mission scrub.

6.2.6.10 Safety

For the safety considerations of spray-foam, see Paragraph 6.1.4.10.

6.2.6.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. There are no data available on hours required per square foot

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement – 5 weeks.

Subassembly – 0.

Installation – 1 week.

Checkout -- 0.

c. Weight: The total as-installed weight is 0.282 lb/ft^2.

1. MB0130-007 foam, 1.00 inch thick 0.167 lb/ft^2
2. MB0130-023 Type II nylon 0.0546 lb/ft^2
3. MB0120-023 adhesive 0.0600 lb/ft^2

d. Thermal Performance: The Q of this system is 80 $Btu/hr/ft^2$; pK is 0.051 $Btu/lb/hr-°F-ft^4$.

6.3 HIGH-TEMPERATURE PROTECTION

6.3.1 Rigid Heat Shield – HRP Honeycomb, Glass/Phenolic Facing Sheets

6.3.1.1 Description

On the S-II, a thermal barrier is installed to protect the base region from excessive heating during S-II boost (V7-530401). This barrier, called the base heat shield, consists of two parts: the rigid portion described in this section and the flexible curtains described in Section 6.3.4. The rigid heat shield, located between the J-2 engines, provides thermal protection for the thrust cone, the thrust-cone-mounted equipment, and the LOX tank.

Thermal protection is achieved by deflecting and diverting engine exhaust plumes. At high altitude, the exhaust plumes expand and impinge on one another at a short distance from the nozzle exit plane. The pressure rise resulting from the supersonic impingement causes a back flow of exhaust gases into the base region. At low altitude, the exhaust plumes do not expand as much as at high altitude, and no jet impingement occurs. The back flow of exhaust gases cause considerable base heating. In addition to this convective heating, radiative heat will be emitted by the exhaust gases. At sea level, convective heating from the exhaust gases is negligible, but radiative heating can be appreciable.

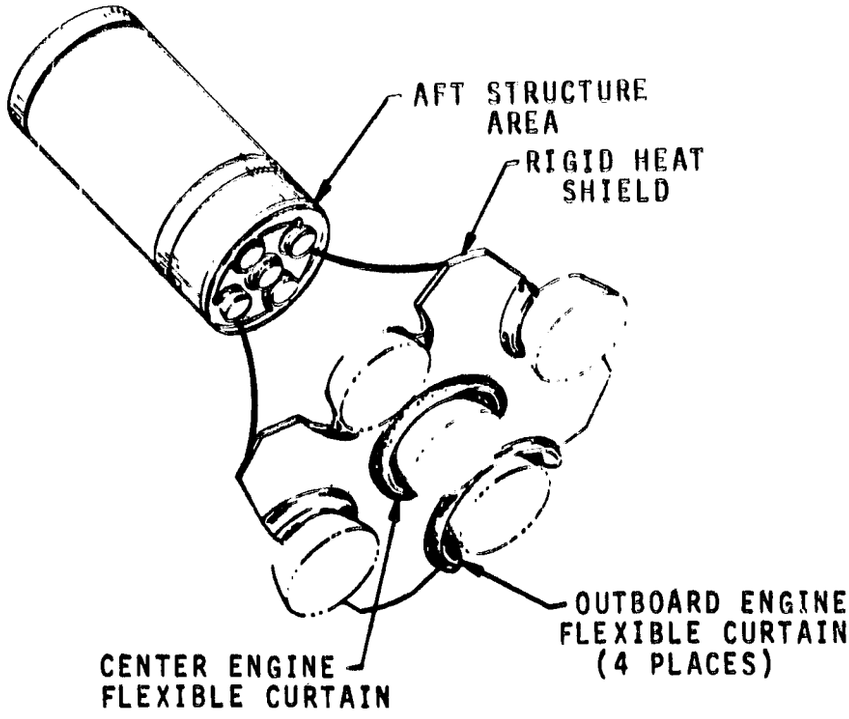
The location of the heat shield is shown in Figure 6.3.1.1-1. A cross-section of the heat shield and materials used in its construction are shown in Figure 6.3.1.1-2.

6.3.1.2 Application

a. Utilization: The rigid heat shield, made of honeycomb core filled with glass microspheres and with glass/phenolic facing sheets, protects thermal-sensitive components and materials against high radiant and convective heating during firing of the S-II engines. Thermal performance is achieved through the insulating characteristics of the microspheres. To prevent premature loss of the facing sheets from overpressurization, holes are drilled in each sheet to vent gases generated within the honeycomb cells.

   This heat shield system is applicable to other space vehicles having similar heating conditions and whose components and structure must be thermally protected.

b. Performance Characteristics: The design shown in Figure 6.3.1.1-2 has been successfully used for all S-II's. Figure 6.3.1.2-1 shows a comparison of the maximum predicted heat shield temperatures, typical for S-II-5 flight, and the maximum design temperature for the aft facing sheet of the heat shield. The design temperature is well above the temperature experienced.



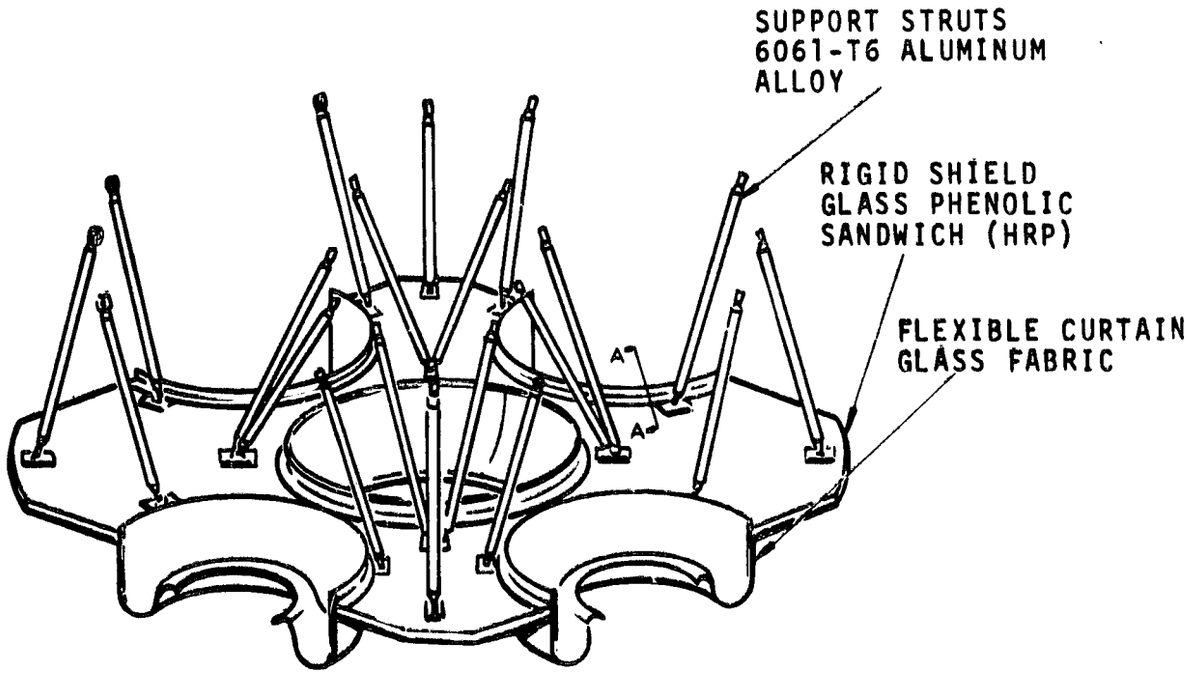


Figure 6.3.1.1-1. General Location of S-II Subsystem

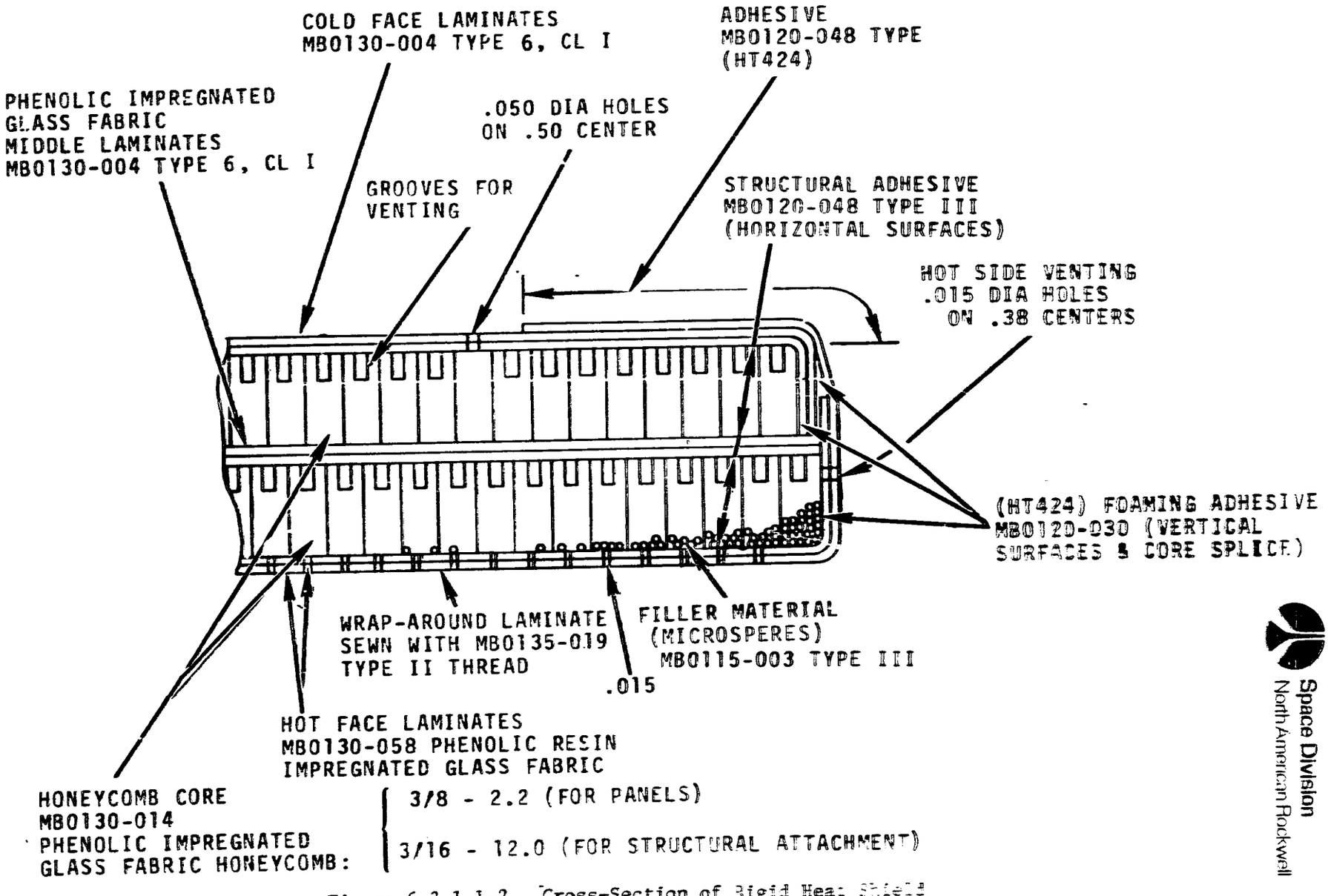


Figure 6.3.1.1-2. Cross-Section of Rigid Heat Shield

Space Division
North American Rockwell

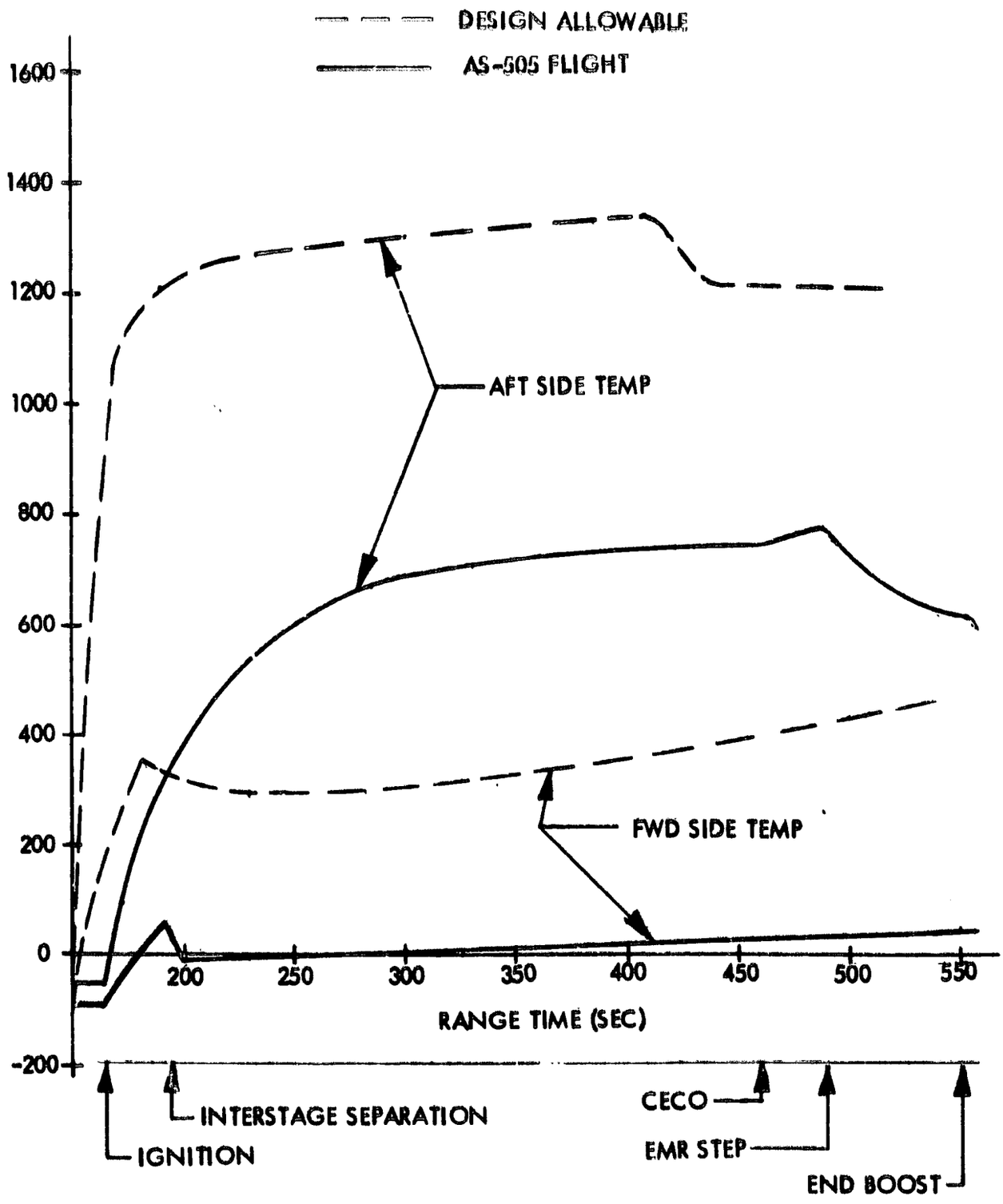


Figure 6.3.1.2-1. Heat Shield Temperature

c. System Limitations: The system was developed to meet the requirements of the S-II. These include the following maximum design temperatures: aft side, 1550 F; middle face side, 500 F; and cold face, 400 F.

d. Design Problems: Problems encountered in heat shield design, all relatively minor, are listed in Table 6.3.1.2-1.

Table 6.3.1.2-1. Heat Shield Design Problems and Solutions

Problem	Resolution
Pressure buildup in panel at temperature due to material outgassing	Vented configuration by drilling holes in each core cell
Failure of attach points because of shallow threads	Made special bolt with additional lockwire holes and extended length of bolts
Damage to inserts during attachment of clamps and fixtures; gap between insert and upper laminate	Redesigned inserts so they were flush with upper laminate

e. Verification Tests: Simulated heating and vibration tests were conducted on 4- by 4-foot panels of the heat shield design to provide verification and initial qualification. Successful results were obtained on three panels tested. Based on these tests, the system was considered satisfactory for first flight, with full qualification dependent on successful performance.

6.3.1.3 Thermal Performance

The important performance requirement of the rigid heat shield design is that it be capable of withstanding the temperature distributions that result from base heating rates during boost. The predicted heating rates are presented in Figure 4.2.2.3-3. The thermal analysis conducted included the effects of base heating on the heat shield supports and rigid shield splice plates. The duration of these base heating periods in the analysis were 374 seconds for the dual and single actuator failure cases, and 467 seconds for the outboard engine out failure case. These two failures result in the most severe base heating rates. The propellant mixture ratio (PMR) used for dual and single actuator failure heating condition was 5.5:1 for the first 295 seconds, and 4.7:1 for the remaining portion of S-II boost. The PMR used for the outboard engine out failure case was the same except reduction to 4.7:1 occurred at 367 seconds. The application of these ratios and times was significant in providing the heating rates assumed in the analysis, which are shown in Figure 4.2.2.3-3.

For analysis purposes, the rigid heat shield was divided into zones to account for variances in the heating rates and view factors. These heating rates, along with the thermal and material properties, were then used as input data to a general heat transfer analysis computer program to determine temperature responses throughout S-II boost for all zones. The heat transfer modes used in the analysis were convective heating, radiant heating, radiation interchange, and conduction.

Typical temperature responses for the rigid portion of the heat shield are shown in Figure 6.3.1.3-1. They indicate that the rigid heat shield meets the temperature requirements. Detailed temperature responses of other zones are presented in the section on thermal performance analysis.

6.3.1.4 Structural Performance

Critical loading on the base heat shield results from dynamic loading and thermal stresses. Vibrational loading occurs in the longitudinal, radial, and tangential directions. Conventional methods of analysis for honeycomb sandwich construction are used for structural analysis of the heat shield. Significant factors affecting the selection of the design are:

a. Sandwich facings must be at least thick enough to withstand the chosen design stresses under the design load.

b. The core must be thick enough and have sufficient shear rigidity and strength so that overall sandwich buckling, excessive deflection, and shear failure will not occur under design loads.

c. The core must have high enough modulus of elasticity, and the sandwich must have great enough flatwise tensile and compressive strength, so that wrinkling of either facing will not occur under the design loads.

d. If dimpling is not permissible, the cell spacing must be small enough to prevent dimpling of the faces under design load.

6.3.1.5 Materials and Processes

a. Materials:

1. Honeycomb: The core is a nonvented 3/8-inch cell fabricated of glass fabric impregnated with heat-resistant phenolic resin (MB0130-014).

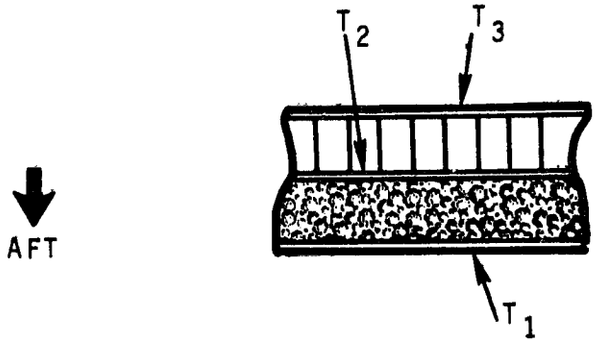
2. Fabric:

(a) Glass fabric, phenolic preimpregnated (MB0130-004).

(b) Glass fabric, phenolic preimpregnated, high temperature (MB0130-058).

(c) Temperature-resistant silica thread (MB0135-019).

(d) Glass microsphere particles (MB0115-003).



NOTES:

1. HEATING RATES FOR DUAL ACTUATOR FAILURE
2. RIGID SHIELD SECTION R-10

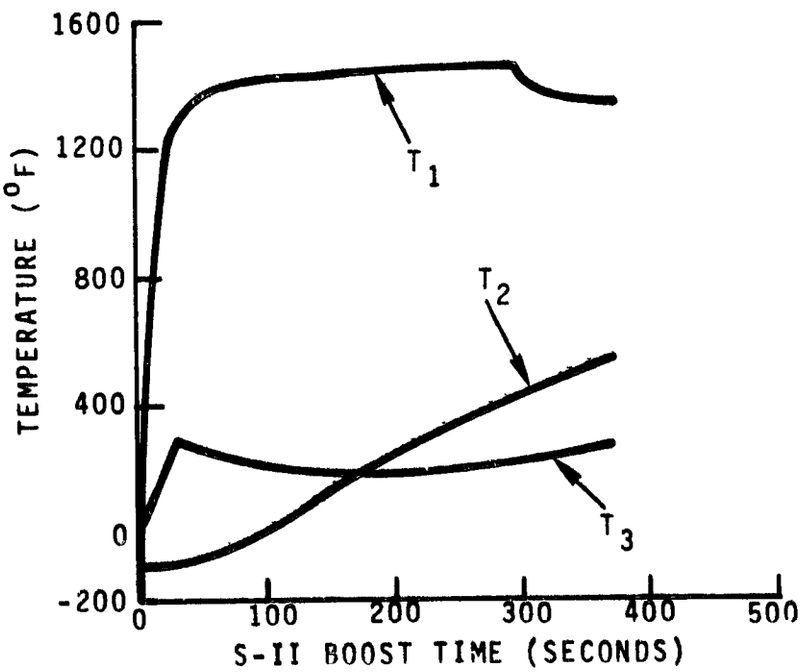


Figure 6.3.1.3-1. Typical Rigid Shield Section

3. Adhesive:

   (a) Thixotropic paste adhesive (MB0120-026).

   (b) Foaming-type paste, elevated temperature-resistant (MB0120-030).

   (c) Epoxy-phenolic glass-fabric-supported tape adhesive (MB0120-048).

b. Processes: Storage, handling, and processing of the materials used to fabricate the base heat shield are described in Section 11.

1. Fabrication of Base Heat Shield (MA0605-001):

   (a) Fabrication of Laminate Face Sheets: The same precautions are required in fabricating the glass fabric laminate face sheets that are observed in constructing the basic insulation system (Paragraph 6.1.1.5). The overlaps of the glass fabric are at least one inch, except in areas where part configuration prohibits this size. The overlaps on the hot side are also sewn with a silica thread for stress purposes. The laminates are cured by elevating the temperature in six steps, until a temperature of 300 F is reached; they are then held at temperature for at least 1 hour. The laminate is cooled to 150 F before the pressure is removed.

   (b) Fabrication of Honeycomb Core: Procedures followed in machining the core configuration and grooves and fitting the splice joints are the same as those outlined in Paragraph 6.1.1.5.

   (c) Filler: Glass microsphere particles are packed in each cell by shaking or vibrating. In these areas, at least 100 grams of filler is used per square foot per inch of thickness of honeycomb core.

   (d) Bonding of Components: The surfaces of the glass laminates that are to be bonded are lightly scuff-sanded with 120-grit sandpaper. Care must be taken not to sand through the glass layers. The laminate facing is bonded to the honeycomb core with an epoxy-phenolic adhesive. Bonding of the lateral edges of the honeycomb core to the laminate and of honeycomb core to honeycomb core is accomplished with foaming-type adhesive. Adhesive patterns are tailored prior to removal of the protective film. The adhesive may be chilled with dry ice to facilitate removal of the film. Pressure is applied by the vacuum bag technique, with a minimum vacuum of 20 inches of mercury maintained throughout the cure cycle. Provision must be made for bleed-off of volatile materials, and the vacuum bag must be free of leaks. The cure temperature is raised in three steps until 340 F is reached, which is held at least 1 hour. The panel assembly is cooled to 150 F, at which point the vacuum may be removed.

(e) Potting of Heat Shield Components: For installation of inserts and attachments, holes are drilled in the heat shield in accordance with the applicable engineering drawing. Care must be exercised during the drilling operation not to cause delamination of the laminate around the periphery of the hole. The potting material, thixotropic paste, must be cured in a circulating-air oven for at least 1 hour at 340 ± 10 F.

6.3.1.6 Manufacturing

a. Description: The complexity in manufacturing the rigid heat shield is in the many manufacturing processing operations involved in its assembly. The key operations are shown in the manufacturing flow (Figure 6.3.1.6-1). The 1-inch panel halves are fabricated first, then the center skin is bonded to the cold side. The cold side is fitted to the somewhat larger hot side and bonded. A final wraparound skin ties the hot side and cold side together on the periphery. The holes and inserts are then installed by potting. The most manufacturing effort is in layup- and bonding-type operations, which require strict adherence to in-process controls. All work must be done in an environmentally controlled area as cleanliness is most essential to a reliable assembly. The layup and curing operations must be carried out within the time limits and temperatures of the specifications.

b. Tooling and Equipment: The principal tools are as follows:

Cold-side panel layup die
Hot-side panel layup die
Flat bond table
Drill templates and jigs
Miscellaneous adhesive tools and slotting saws

The primary pieces of equipment required are a bonding oven capable of maintaining a constant temperature of 340 F and a vacuum source for the bonding bag pressure (approximately 14 psi).

6.3.1.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control: The engineering requirements and quality assurance provisions were established by MA0605-001.

1. Honeycomb Core: The core material was inspected for dimensional conformance with the thickness requirements specified on the engineering drawing.

2. Laminate Visual Inspection: Each laminate was visually inspected for evidence of the following unacceptable defects:

   (a) Fractures

   (b) Holes (except as specified on the drawing, no holes were allowed which penetrated through any layer of glass fabric)

   (c) Blisters

   (d) Starved areas (defined as areas in which the fabric was not sufficiently impregnated with resin)

   (e) Tack: the entire laminate was verified to be tack-free.

   (f) Wrinkles: no wrinkles were allowed on the external heat shield laminate; wrinkle allowables were established for the internal laminates as long as the wrinkle did not exceed 0.020 inch in height.

   (g) Delaminations

   (h) Foreign objects

3. Bonded Sandwich Visual Inspection: All bonded production parts were inspected for exterior indication of improper cure, poor adhesion, improper alignment, dents, fractures, or other visible flaws.

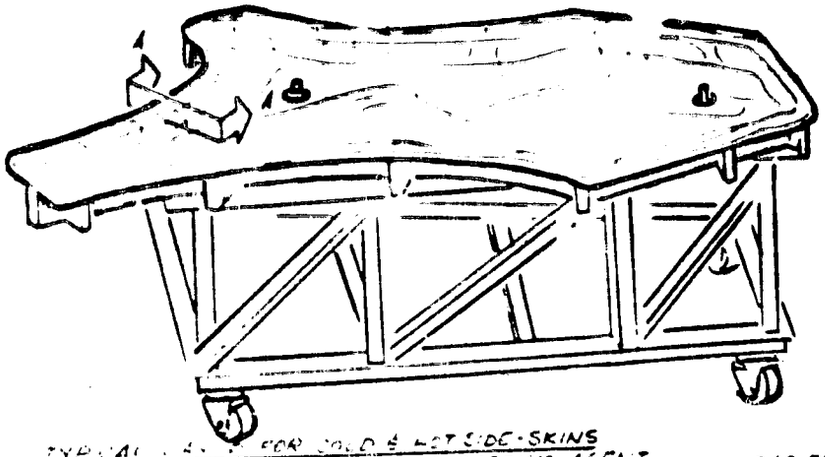
4. Nondestructive Inspection, LQ0501-008: All individual laminated honeycomb panels were inspected for unbond areas using a sonic resonator employing a glycerin couplant. The inspection was performed prior to drilling the panel outgassing vent holes (Figure 6.3.1.1-2). The inspection was performed by masking off each detail into 12-inch grids. As each area was inspected, the maskant was removed. Laboratory "standards" were fabricated with known void areas for comparison with production details.

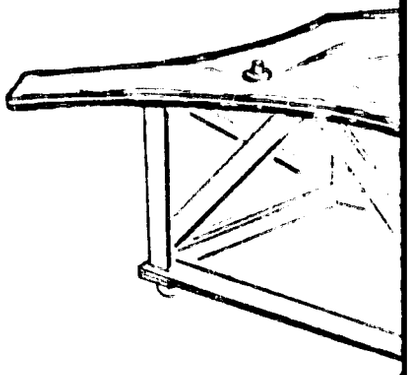
5. Process Verification Coupons: With the exception of thixotropic paste materials, all bonding operations required that test coupons be fabricated simultaneously with the production parts for testing and part acceptance.

   (a) Laminating Coupons: Laminate coupons were tested for tensile strength, resin content, and specific gravity.

   (b) Bonding Coupons: Bonding coupons were tested for lap shear strength, honeycomb tensile, and honeycomb peel.

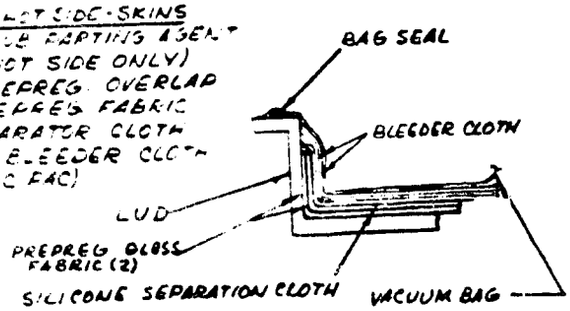
c. Final Installation Fit Check, MA0308-1018: Upon completion of production operations a final fit check was performed by installing the heat shield on the S-II stage. Inspection verified no interference with any components such as wire bundles, brackets, and supports, while the engines were





TYPICAL LAYUP FOR COLD & HOT SIDE SKINS

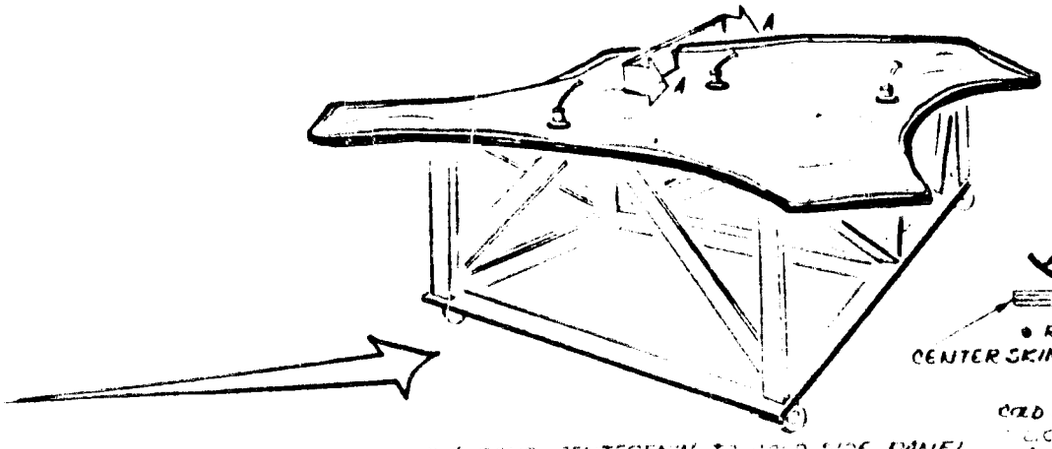
- WIPE LOCATION CLEAN AND RUB PARTING AGENT
- PLACE DISCS INTO DIE (HOT SIDE ONLY)
- LAYUP GLASS FABRIC PREPREG. OVERLAP
- LAYUP 2ND LAYER PREPREG FABRIC
- INSTALL SILICONE SEPARATOR CLOTH
- INSTALL TWO LAYERS BLEEDER CLOTH
- INSTALL VACUUM BAG (VAC FAC)



LAYUP OF CENTERSKI

- WIPE FLAT BOND TAB
- LAYUP (4) LAYERS
- INSTALL SILICONE
- INSTALL TWO LAYE
- INSTALL VACUUM B

1



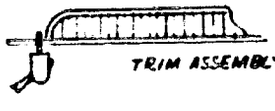
PEEL P

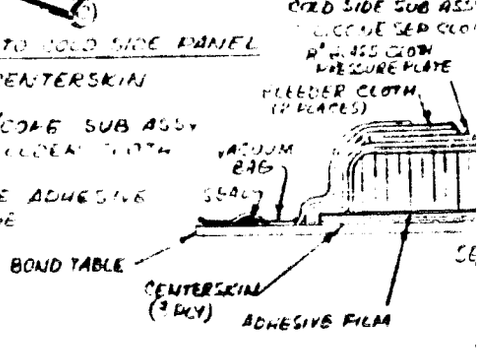
• REMOVE PEE

CENTERSKIN

LAYUP & BOND CENTERSKIN TO COLD SIDE PANEL

- REMOVE PEEL PLY FROM CENTERSKIN
- APPLY ADHESIVE FILM
- INSTALL COLD SIDE SKIN/CORE SUB ASSY
- INSTALL SEPARATOR & BLEEDER CLOTH
- INSTALL VACUUM BAG
- MOVE TO OVEN AND CURE ADHESIVE
- TRIM OFF EXCESS FLANGE

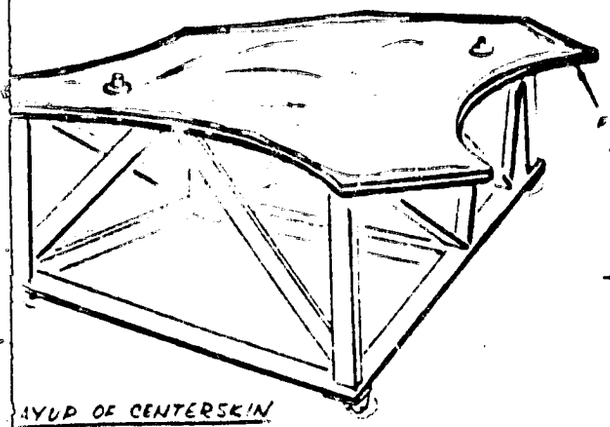




7

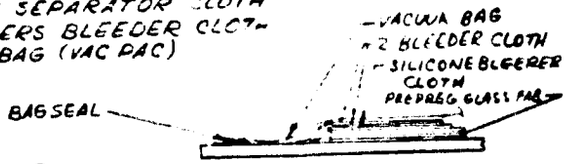
FOLDOUT FRAME

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



AYUP OF CENTERSKIN

WIPE FLAT BOND TABLE CLEAN
AYUP (4) LAYERS OF PREPREG GLASS FABRIC
NSTALL SILICONE SEPARATOR CLOTH
NSTALL TWO LAYERS BLEEDER CLOTH
NSTALL VACUUM BAG (VAC PAC)



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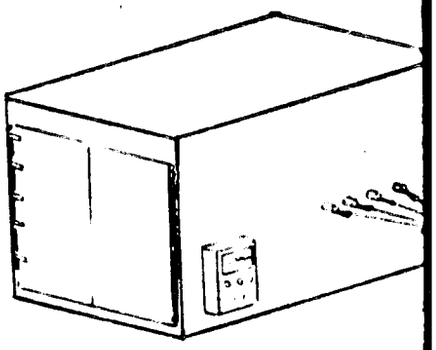
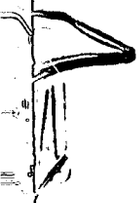
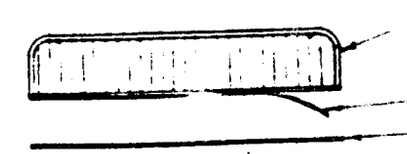


OVEN CURE

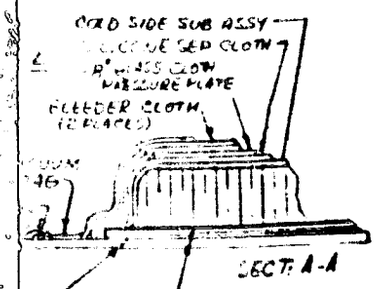
3

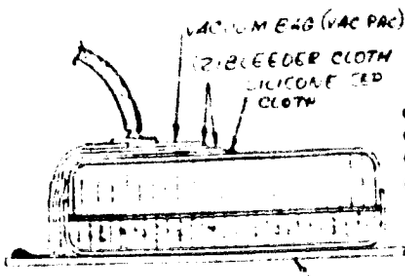




• REMOVE PEEL PLY

ITER SKIN



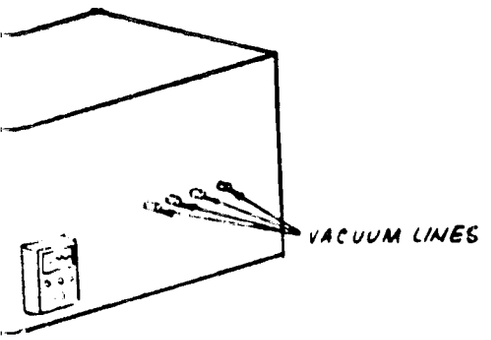


BOND COLD SIDE TO HOT SIDE

- PEEL HOT SIDE LINE WITH MICROSPHERES
- PEEL PLY FROM COLD SIDE CENTER SKIN
- APPLY ADHESIVE FILM TO CENTERSKIN
- APPLY FOAM PASTE TO FLANGES AND FILLETS
- MATE HOT & COLD SKIN ASSEMBLIES
- VACUUM BAG & OVEN CURE

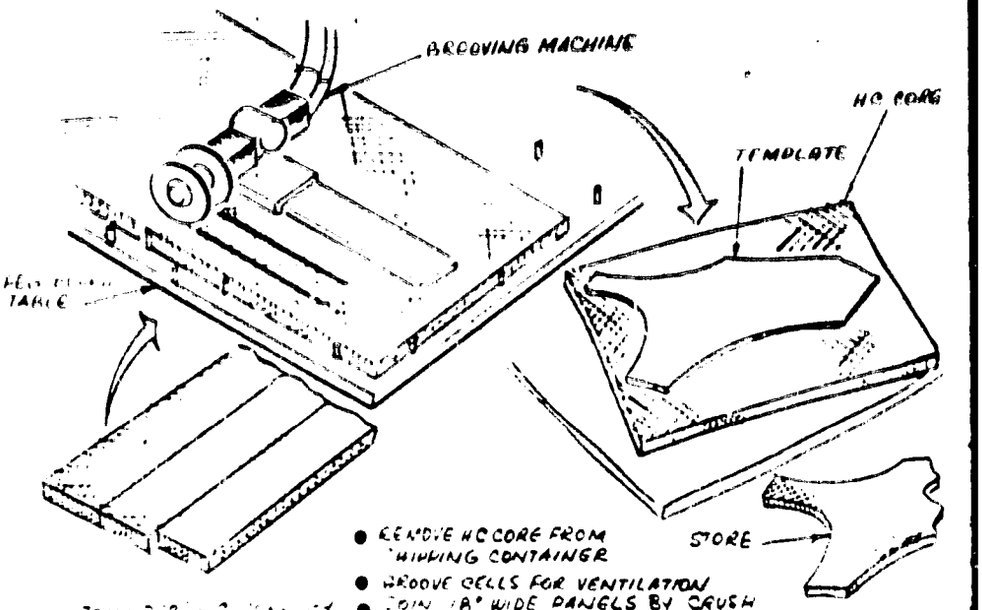
8

FOLDOUT FRAME 2



OVEN CURE

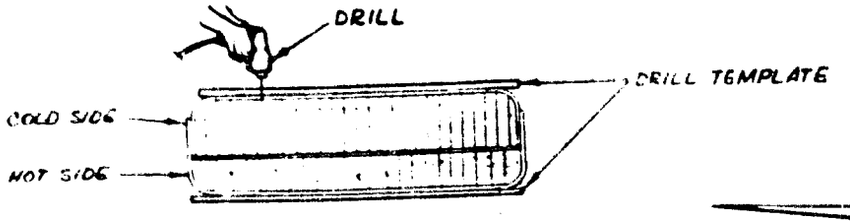
3

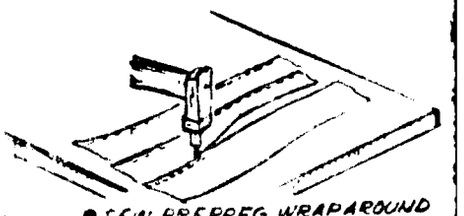


- REMOVE HC CORE FROM SHIPPING CONTAINER
- GROOVE CELLS FOR VENTILATION
- JOIN 18" WIDE PANELS BY CRUSH SPLICING (3/8" CORE ONLY)
- APPLY TEMPLATE AND CUT PERIPHERY
- GRIND 3/8" RADIUS AROUND PERIPHERY

4

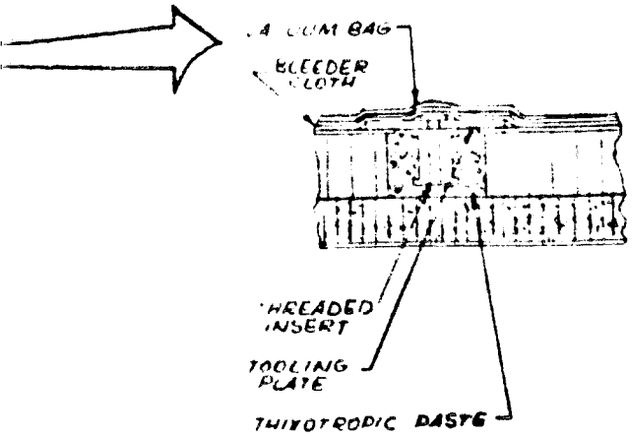
HONEYCOMB FABRICATION





- SEW PREPREG WRAPAROUND TO MAKE SINGLE SHEET

NOTE: STORE UNDER FREEZER UNTIL USED ON LAYUP

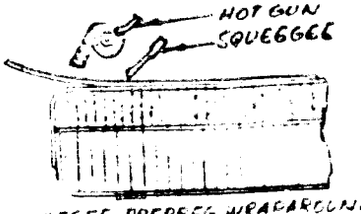


DRILL HOLES FOR INSERTS

- DRILL PILOT HOLE
- COUNTERBORE SKIN
- GRIND OUT CORE

LAYUP & BOND THREADED INSERTS

- FILL HOLE WITH THIXOTROPIC PASTE
- INSTALL THREADED INSERT
- BOLT TOOL PLATE
- VACUUM BAG & OVEN CURE



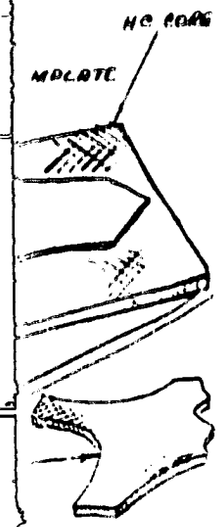
- SQUEEGEE PREPREG WRAPAROUND TO PANEL

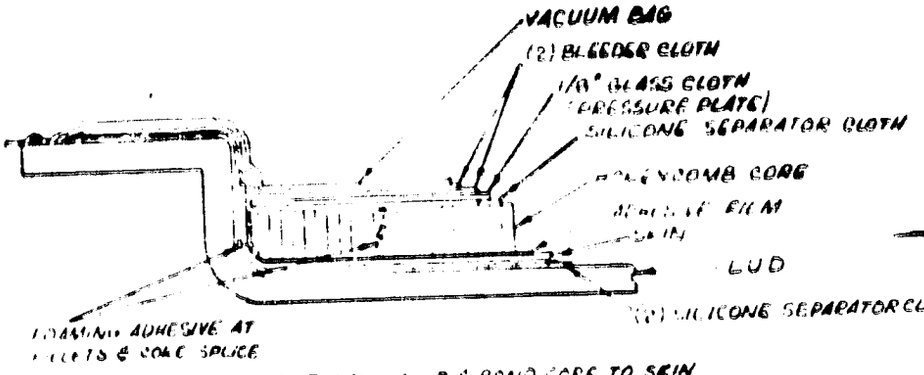
WRAP AROUND SKIN LAYUP

- LAYUP
- INSTALL BLEEDER CLOTH & VACUUM BAG
- BOND IN OVEN

9

FOLDOUT FRAME 3





TYPICAL LAY UP & BOND CORE TO SKIN

1. LAYUP DETAILS IN BENCH WHILE TOOL IS BEING PREHEATED TO 200°F (OVEN)
2. INSTALL LAYUP IN LUD
3. COMPLETE BAGGING OPERATIONS
4. MOVE TO OVEN FOR CURE

5

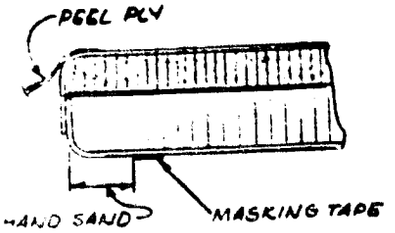
HERY
RIPHERY

EG WRAPAROUND
INGLE SHEET
LDER RECEIVE
USED ON LAYUP
HOT GUN
SQUEEGEE

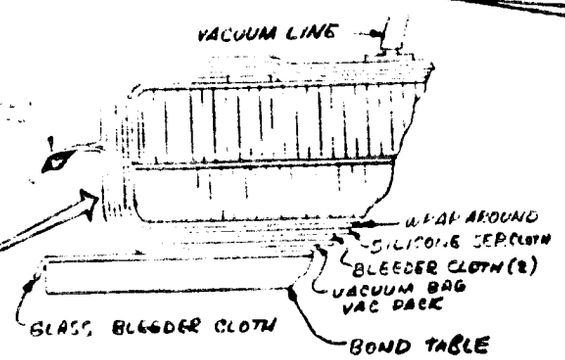
G WRAPAROUND

KIN LAYUP

LDER CLOTH
AG
VEN



- PREPARE SURFACES TO RECEIVE WRAPAROUND MATERIAL

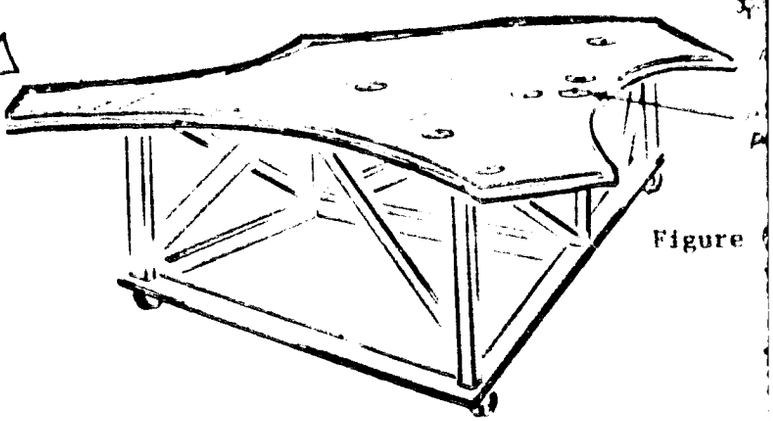


INSTALL WRAPAROUND SKIN

10

FINAL INSTALLATIONS

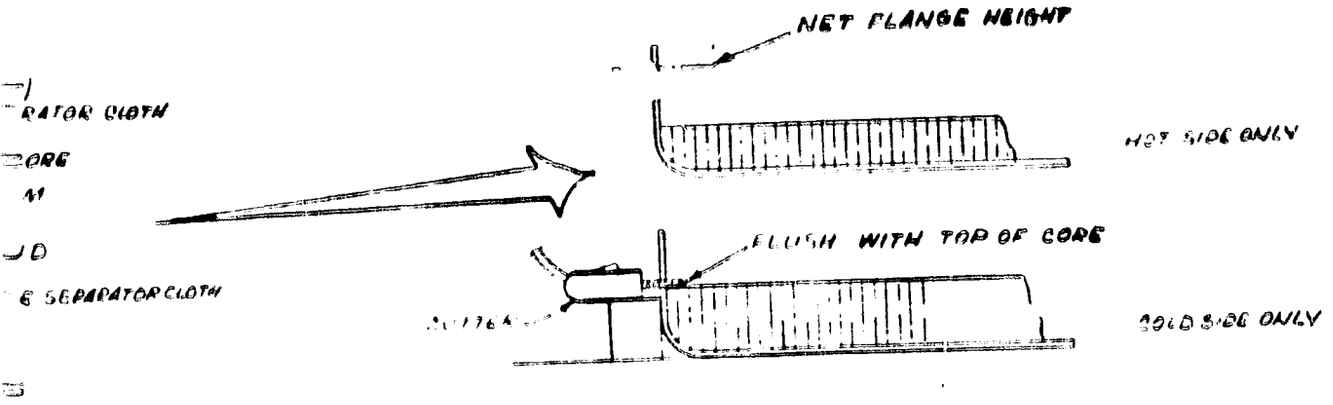
- DRILL & BOND REMAINING INSERTS & PLUGS
- BOND SPACER PADS OVER ATTACH HOLES
- DRILL BOOD HONEY COMB VENT HOLES (HOT SIDE ONLY)
- INSTALL BRACKETRY
- PAINT 1/4" BOLTS



Figure

11

FOLDOUT FRAME 4



TRIM FLANGES

6

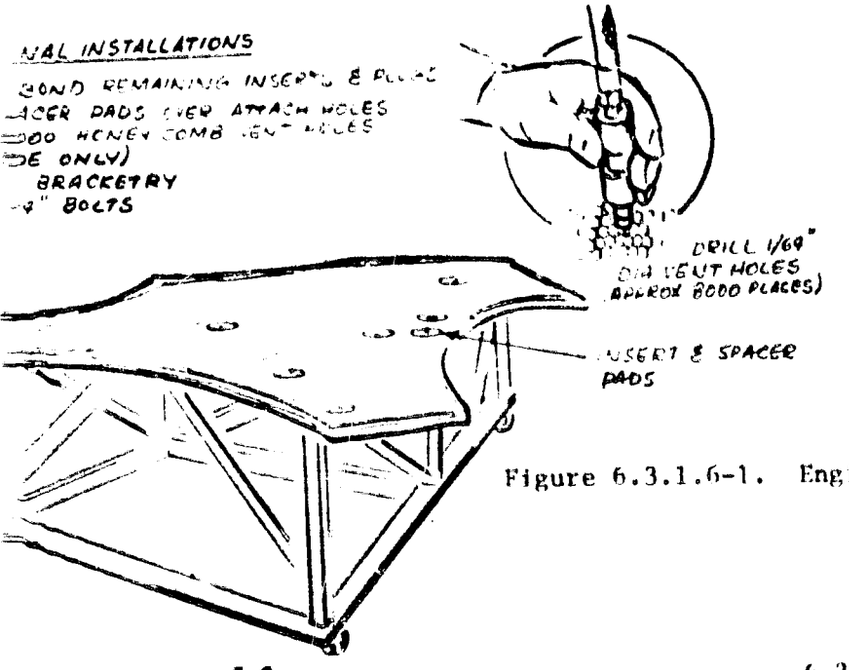


Figure 6.3.1.6-1. Engine Base Heat Shield Panel Flow Diagram

subjected to a complete gimbal cycle. When proper fit was verified, the heat shield was removed, packaged, and shipped to KSC for installation on the vehicle following complete stacking of the Saturn V vehicle.

6.3.1.8 Repair and Maintenance

a. Repair: All repairs require Material Review Board approval. Specification MA0606-048 defines repair procedures for insert holes, replacement of inserts, laminate, and core for the hot and cold sides of the heat shield.

b. Maintenance: No special maintenance is required.

6.3.1.9 Reliability

Two failure modes were identified: heat leak and loss of adhesion. FMEA results are presented in Table 6.3.1.9-1.

Table 6.3.1.9-1. FMEA-HRP Honeycomb, Glass/Phenolic Facing Sheets

Subsystem or Component	Failure Mode	Mission Effects Remarks
Heat Shield	Heat Leak	Overheating of components in the thrust structure area
	Loss of Adhesion	Honeycomb laminate separation; overheating of components, heat shield structure loss

6.3.1.10 Safety

a. Fabrication and Installation: During fabrication of the base heat shield, operations must be conducted in accordance with the applicable sections of Industrial Safety Operations Standards.

Toxic, caustic, and flammable materials are used in the fabrication of this insulation system. Personnel handling these materials should be trained in their use and carry a valid certification of this training.

Flammable dust and debris result from cutting and sanding operations. To minimize fire hazards and prevent contamination, appropriate attention should be given air filtering and housekeeping.

Glass fibers are produced when the curtain and glass/phenolic honeycomb are cut or sanded. Protective clothing should be worn by operating personnel to protect the skin, and breathing masks should be worn to protect the throat and lungs.

During installation of the base heat shield, the support struts should be carefully adjusted to ensure that no torsional or bending loads are introduced into the heat shield.

While the heat shield is being installed, care should be used to ensure that tools or parts of the heat shield are not dropped onto lower portions of the stage.

b. Using the Base Heat Shield: When the heat shield is installed and is being used as a work platform, care should be taken to prevent the dropping of tools or equipment onto it. A sharp impact might delaminate the skin from the core. While this damage may not be apparent, it could lead to failure in flight.

6.3.1.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the heat shield's relative cost: 75 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 12 weeks.

Subassembly - 21 weeks.

Installation - 2 weeks.

Checkout - 0.

c. Weight: The total as-installed weight is 1.05 lb/ft^2 broken down as follows:

1. Glass/phenolic fabric, 2 layers (MB0130-004 Type 6 CL I) - 0.1930 lb/ft^2
2. Honeycomb, 3/8-inch cell, two 1-inch-thick layers (MB0130-014) - 0.3658 lb/ft^2
3. Glass/phenolic, 2 layers (MB0130-058) - 0.1980 lb/ft^2
4. Microspheres, 2.5 lb/ft^3, 0.5 inch thick (MB0115-003 Type III) - 0.1044 lb/ft^2
5. Glass phenolic fabric, 2 layers (MB0130-004 Type 6, CL I) - 0.1930 lb/ft^2

d. Thermal Performance: Q is not applicable to the base heat shield because of the varying heating rates from the engines and the short time span of the heating; PK is 0.283 Btu/lb/hr-°F-ft^4.

6.3.2 Rigid Heat Shield HRP Honeycomb/Phenolic Facing Sheets, Silica Mat

6.3.2.1 Description

This rigid heat shield design was proposed in an S-II derivative study to meet base heating rates more severe than those experienced on the S-II. The basic heat shield is the same as that described in Section 6.3.1. A high silica mat is added on the hot-face side, as shown in Figure 6.3.2.1-1, to increase the thermal protection.

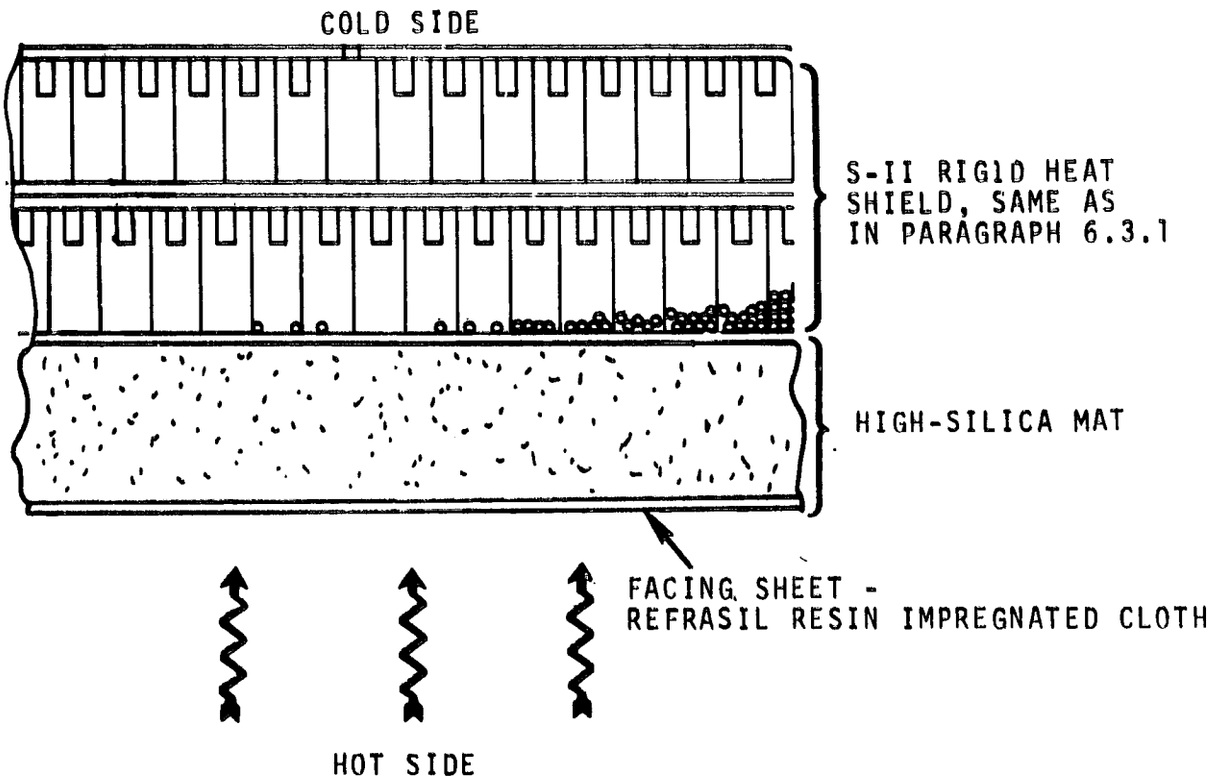


Figure 6.3.2.1-1. Cross-Section of Rigid Heat Shield Plus Refrasil Facing Sheet

6.3.2.2 Application

a. Utilization: This system, an adaptation of the heat shield discussed in Section 6.3.1, has not been used on the S-II program, but the technique could be used to modify existing proven designs and extend their applications.

b. Performance Characteristics: Although no tests have been conducted on this system, performance can be extrapolated from performance of the system described in Section 6.3.1 in applications with hot-side temperatures of approximately 1600 F.

c. System Limitations: Limitations of this system must be considered the same as those in Paragraph 6.3.1.2, with the increase in temperature to 1600 F on the hot side. Laboratory tests may extend this limit.

d. Design Problems: See Paragraph 6.3.1.2.

e. Verification Tests: No tests have been conducted.

6.3.2.3 Thermal Performance

The important performance requirement of the rigid heat shield is that it be capable of withstanding a maximum surface temperature of 1650 F. The heating environment on the rigid portion of the heat shield is assumed to consist of a maximum convective heating rate of 20 Btu/ft^2-sec and a radiative heating rate of one Btu/ft^2-sec. The gas recovery temperature assumed is 2345 F. The temperature on the aft face of the heat shield due to these environments, is approximately 1600 F.

6.3.2.4 Structural Performance

Structural prime drivers in the proper design of the rigid heat shield with silica mat are identical to those given for the S-II base heat shield in Paragraph 6.3.1.4. In addition, the silica mat must have strain compatibility with the rigid heat shield so that tearing or gross deformation will not occur at attachments.

6.3.2.5 Materials and Processes

This heat shield was proposed for applications in which elevated temperature would be encountered. The study did not require verification of the proposed concept, and no procedures or techniques were developed by the Materials and Processes group.

6.3.2.6 Manufacturing

No Manufacturing data are available.

6.3.2.7 Quality Assurance

This design did not reach production status during the course of the S-II program. Therefore, no quality control procedures were established for the total insulation composite. Quality assurance provisions for the rigid heat shield portion of the composite are included in Paragraph 6.3.1.7.

6.3.2.8 Repair and Maintenance

No standard repair and maintenance procedures were developed.

6.3.2.9 Reliability

There has been no failure mode effects analysis generated for this type of insulation.

6.3.2.10 Safety

As stated, this insulation system has not been fully developed. Since no detailed hazard analysis has been conducted, no overall safety recommendations can be made.

Some of the components and materials of this system, such as HRP, have been analyzed, and experience has been gained in fabrication, installation, and use. Thus, safety recommendations can be obtained from the other insulation systems that incorporate these components. It is not expected that a different combination of components would materially alter the recommendations originally made on a component, but overall evaluation cannot be made without the aforementioned analysis.

6.3.2.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the heat shield relative cost. There are no data available on the hours required per square foot.

b. Schedule: Since this concept has not been developed, no data are available on flow times for procurement, subassembly, installation, and checkout.

c. Weight: The total as-installed weight is 1.287 lb/ft^2.

d. Thermal Performance: Q is not applicable to the evaluation of the heat shield because of the varying heat rates from the engines and the short time span of the heating; ρK is 0.28 $Btu/lb/hr\text{-}^{o}F\text{-}ft^4$.

6.3.3 HRP Honeycomb Core, Glass/Polyimide Facing Sheets

6.3.3.1 Description

This insulation system has been proposed as a thermal barrier to protect an auxiliary propulsion system (APS) from the base heating associated with the boost phase of an Expendable Second Stage or INT-21 launch vehicle. The hot-side facing sheet of the barrier deflects the hot exhaust gases, and the space between facing sheets provides thermal resistance to heat transfer from the hot-side facing sheet to the cold-side facing sheet.

This design is shown in Figure 6.3.3.1-1. A heat-resistant phenolic honeycomb core and polyimide facing sheets are bonded together to form a rigid sandwich structure. Addition of an ablator has been proposed as a method of increasing

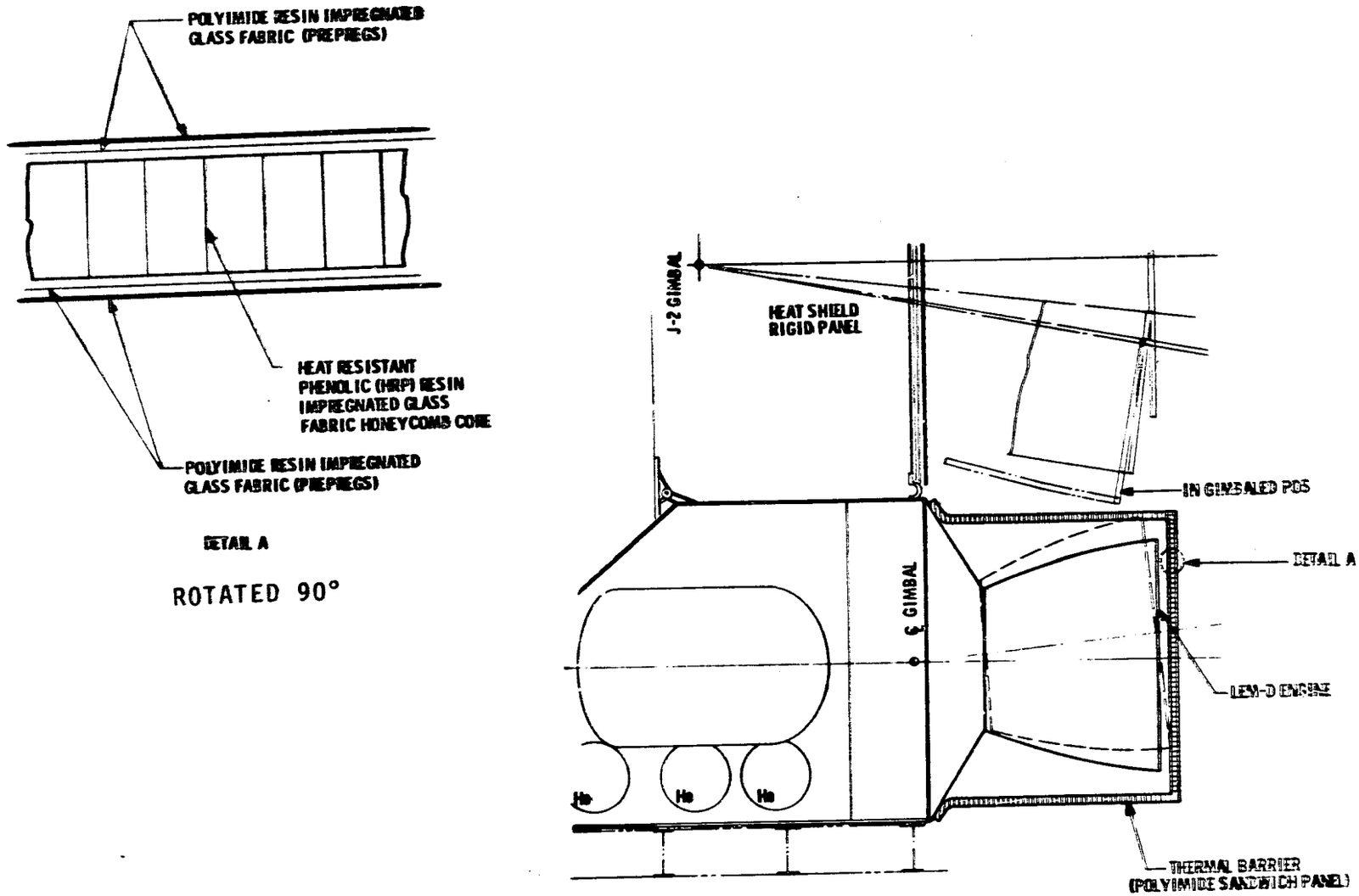


Figure 6.3.3.1-1. Glass/Polyimide Rigid Sandwich Structure

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the thermal capability of the design in local areas where plume impingement could occur due to engine gimbaling.

For additional information on polyimide sandwich panels, see Paragraph 6.1.9.1.

6.3.3.2 Application

a. Utilization: This thermal barrier system is designed to protect sensitive vehicle components from the induced environment of high radiant heat and hot erosional gases such as those due to aerodynamic flight or in areas adjacent to engine plumes.

   The design shown in Figure 6.3.3.1-1 is a unique application for the protection of a specific component. Original development was oriented to the protection of frangible external insulation systems during launch.

b. Performance Characteristics: Systems of this type were evaluated in a design application program (SD 70-684). That effort was devoted to finding a lightweight barrier that could withstand flutter and aeroheating created by a flight profile similar to that of Saturn V.

c. System Limitations: Because of limited test data, this heat shield is not recommended for use in environments where the surface temperature exceeds approximately 1000 F for periods longer than 60 seconds. The addition of ablative coatings such as cork would permit use of the system at higher temperatures, provided the interface with the honeycomb core does not exceed the 1000 F limit.

d. Design Problems: Since this heat shield has not been employed on flight vehicles, design problems associated with installation are not available. Results of design tradeoffs for similar systems are presented in SD 70-684.

e. Verification Tests: No verification tests have been conducted.

6.3.3.3 Thermal Performance

An important thermal requirement of this rigid heat shield is that it be capable of withstanding the temperature responses resulting from the most severe heating environments caused by various failure modes during S-II boost. The maximum temperatures estimated for these worst-case environments for the vertical side and cover of the heat shield are 1460 and 1410 F, respectively. The temperature limit is 1550 F; thus, the shield is capable of withstanding the boost environments considered.

These temperatures do not include that resulting from direct plume impingement, which could result from J-2 engine gimbaling. The temperatures attained in the case of direct J-2 plume impingement upon the heat shield are estimated to range from 2350 to 3250 F. Thus, the heat shield configuration shown in Figure 6.3.3.1-1 is not capable of withstanding direct J-2 plume impingement for any great period. The exhaust gas temperature is about 5000 F. From this it appears that the allowable plume impingement is a time function.

6.3.3.4 Structural Performance

Structural prime drivers in the proper design of the rigid heat shield with polyimide facing sheets are identical to those given for the S-II base heat shield in Paragraph 6.3.1.4.

6.3.3.5 Materials and Processes

This heat shield design did not require verification, and no materials and processes procedures or techniques were developed.

6.3.3.6 Manufacturing

No Manufacturing data are available.

6.3.3.7 Quality Assurance

This insulation did not reach production status during the course of the S-II program. Therefore, no quality control procedures were established for the insulation composite.

6.3.3.8 Repair and Maintenance

No standard repair or maintenance procedures were developed.

6.3.3.9 Reliability

There has been no failure mode effects analysis generated for the insulation.

6.3.3.10 Safety

No detailed hazard analysis has been conducted on this heat shield, and no overall safety recommendations can be made. It is recommended that such an analysis be made on a detailed design as soon as one is formulated.

Some of the components and materials of this system, such as HRP, have been analyzed, and experience has been gained in fabrication, installation, and use. Thus, safety recommendations can be derived from the other insulation systems that use these components. It is not expected that a different combination of components would materially alter the recommendations originally made on a component, but overall evaluation cannot be made without the aforementioned analysis.

6.3.3.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the heat shield's relative cost. No data on required hours per square foot are available.

b. Schedule: Since this heat shield has not been fully developed, no flow times are available.

c. Weight: The total as-installed weight is 1.054 lb/ft^2.

d. Thermal Performance: Q is not applicable to the evaluation of the heat shield because of the varying heat rates from the engines and the short time span of the heating; ρK is 0.28 $Btu/lb/hr-{}^oF-ft^4$.

6.3.4 Flexible Heat Shield–Glass Fabric and Batting

6.3.4.1 Description

The thermal barrier in the base heating region of the S-II consists of the rigid portion described in Section 6.3.1 and the flexible curtains. The latter provide thermal protection for the thrust structure, hardware mounted on the thrust structure, and the LOX tank.

To maintain an effective barrier between the stationary rigid heat shield and the gimbaling J-2 engines, the gap is spanned by flexible curtains composed of a high-temperature-resistant material quilt. Adequate slack is provided to allow for radial movement of the engines and flexing of the curtains due to change in gas pressure during flight.

An overall view of the flexible curtain installation is shown in Figure 6.3.4.1-1. A typical cross section and materials used in curtain construction are shown in Figure 6.3.4.1-2 (complete installation details are shown on V7-530401).

6.3.4.2 Application

a. Utilization: The glass fabric and batting system provides a heat barrier between the engines and the thrust structure and components while allowing movement of the engines. Glass fabric and batting materials are used in other high-temperature applications such as furnaces, heating elements, heating tapes, and electrical insulation.

b. Performance Characteristics: This insulation has been successfully employed on all S-II stages. The system provides the necessary protection for the thrust structure and interstage components. No failure of the system during flight has been indicated.

c. System Limitations: This system was developed to meet the requirements of the S-II program, as discussed in Section 5. The materials and configuration are limited to the constraints of that program. Limitations are based on two major design considerations that prevailed in selection of materials and the design: (1) a maximum temperature of 1650 F and (2) a pressure loading across the composite of 0.1 psi (Figure 6.3.4.2-1).

d. Design Problems: The use of a sewn construction in preparing the system composite considerably reduced the design problems. The only major problem experienced was in manufacturing: excessive fraying of the glass

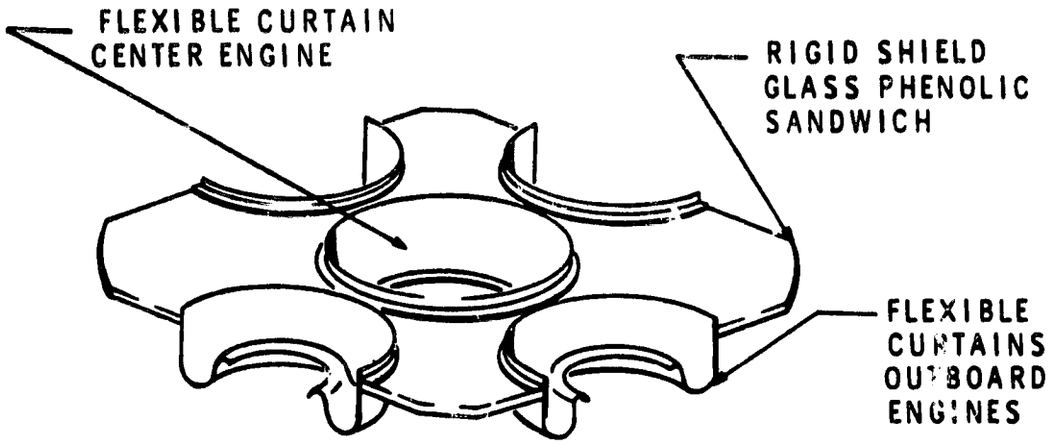

Figure 6.3.4.1-1. Heat Shield Flexible Curtains

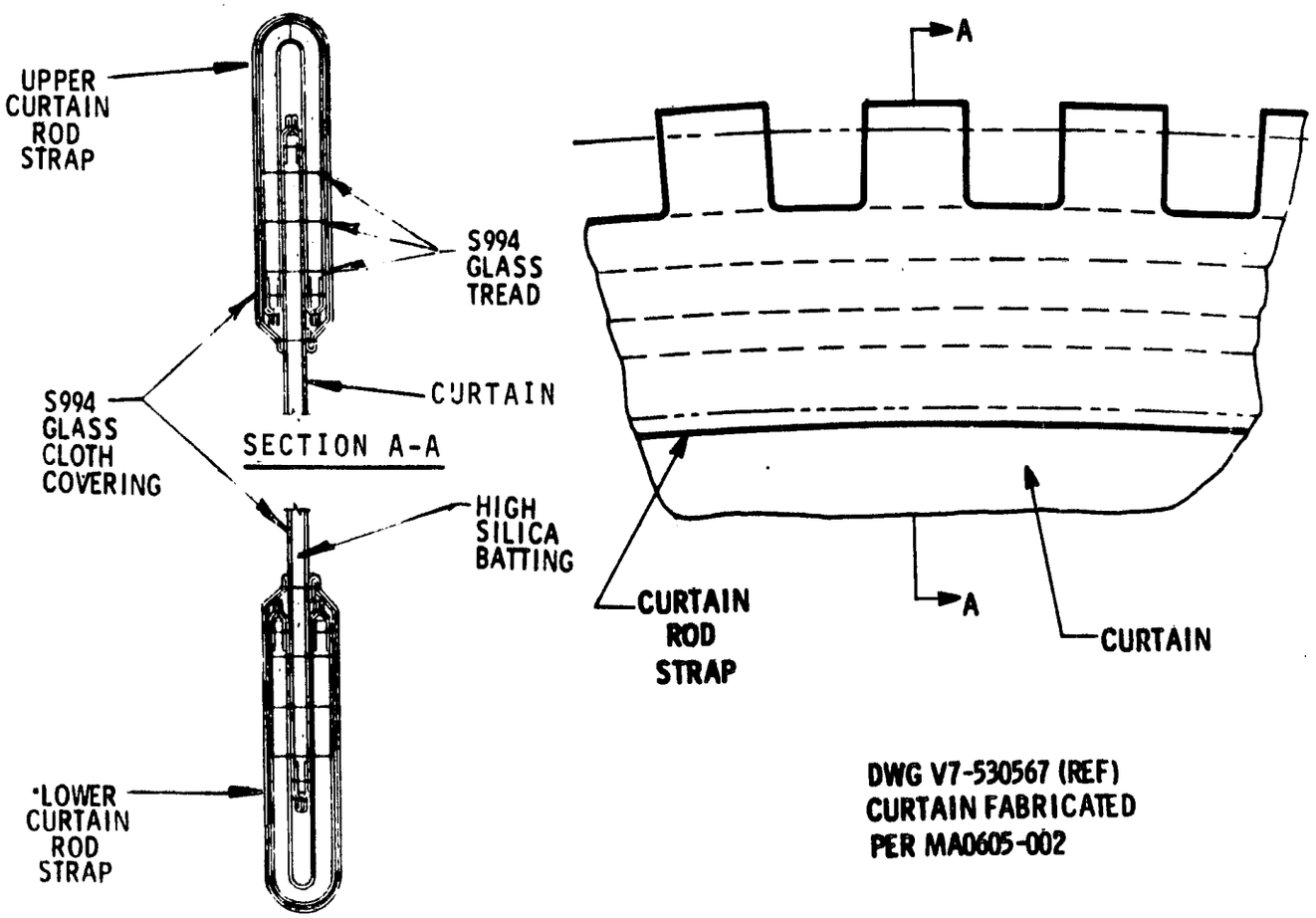

Figure 6.3.4.1-2. Engine Heat Shield Flexible Curtain

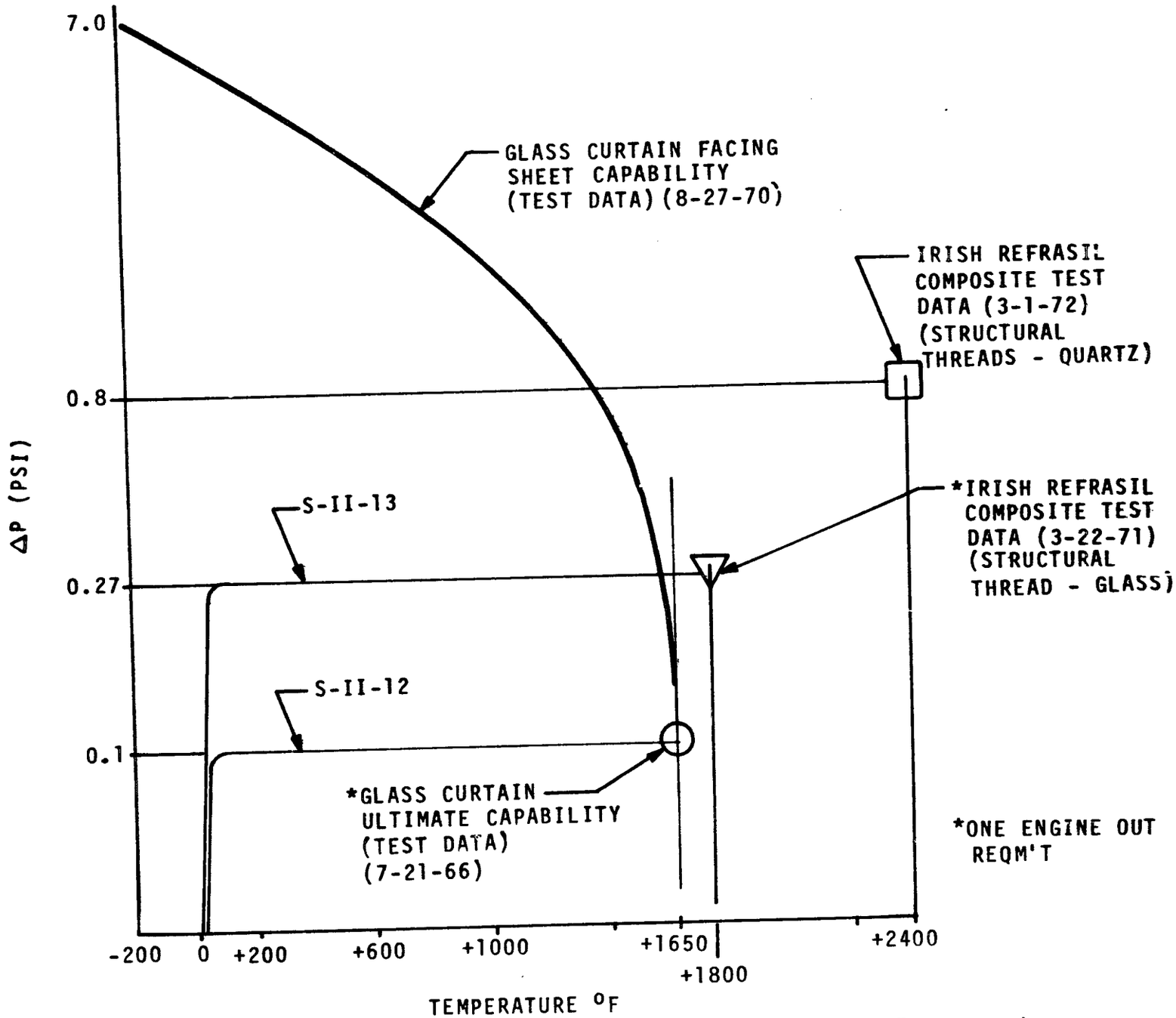

Figure 6.3.4.2-1. Heat Shield Flexible Curtain Tests (Pressure Versus Temperature)

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fabric material during handling. An organic coating was brushed on the glass cloth edges to eliminate fraying during manufacturing. An additional problem was encountered, as demonstrated by test, with the method of attachment. A new edge attachment was designed and successfully demonstrated under test.

e. Verification Tests: Tests to verify the design of the glass cloth/high-silica batting composite are as follows:

1. Verification of Edge Attachments: 6- by 6-foot specimens (Figure 6.3.4.2-2) were tested to ultimate at elevated temperatures. Specimens failed at 36 to 54 psi at 1650 F, in excess of the load requirement of 0.1 psi.

2. Verification of Design Under Heating and Vibration: Tests were conducted on a 48- by 54-inch specimen (SID 63-600-7). The specimen was loaded to 202 pounds and then subjected to sinusoidal vibration or 5-2000 Hz at 45 g's peak at ambient temperature and random vibration (20-2000 Hz at 0.531 g^2/Hz) with aerodynamic heating (1650 F) as shown in Figure 6.3.4.2-3. The specimen showed no apparent damage.

3. Verification of Design Under Tensile Loads: Tests demonstrated that the design could withstand predicted temperature and loading conditions.

4. Flight test data verified adequacy of the system to provide a thermal shield for the thrust structure and interstage components.

6.3.4.3 Thermal Performance

An important performance requirement of the flexible curtain design is that it be capable of withstanding the temperature distributions that result during boost from the base heating rate environment presented in Figure 4.2.2.3-1. The upper temperature failure limit of the flexible curtain is 1650 F.

The curtain was divided into zones to account for the variances in the heating rates and view factors. The environments in these zones, along with the thermal and material properties, were used as input data to a general heat transfer analysis computer program to determine the temperature response in each of the zones. The heat transfer modes used in the analysis were convection heating, radiant heating, radiation interchange, and conduction.

Figure 6.3.4.3-1 presents a typical flexible curtain temperature history for an outboard engine zone and a center engine zone that results from the base heating environment generated by the failure of both hydraulic actuators on one of the J-2 engines. These responses indicate that the flexible curtain meets the temperature requirements imposed by the failure of the dual actuators. Other detailed responses are presented in Paragraph 7.3.4.3.

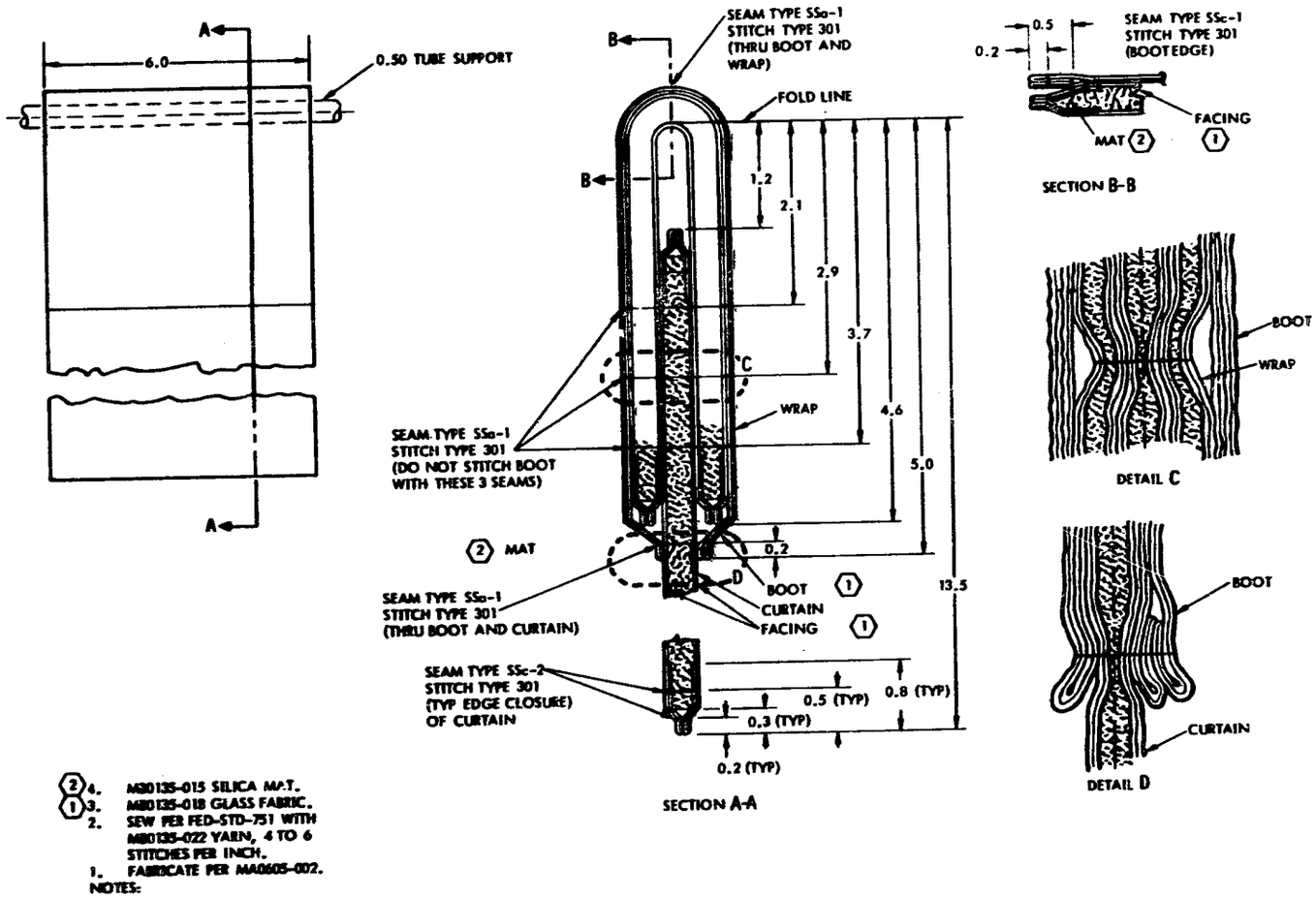

Figure 6.3.4.2-2. Redesigned Curtain Attachment Test Specimen

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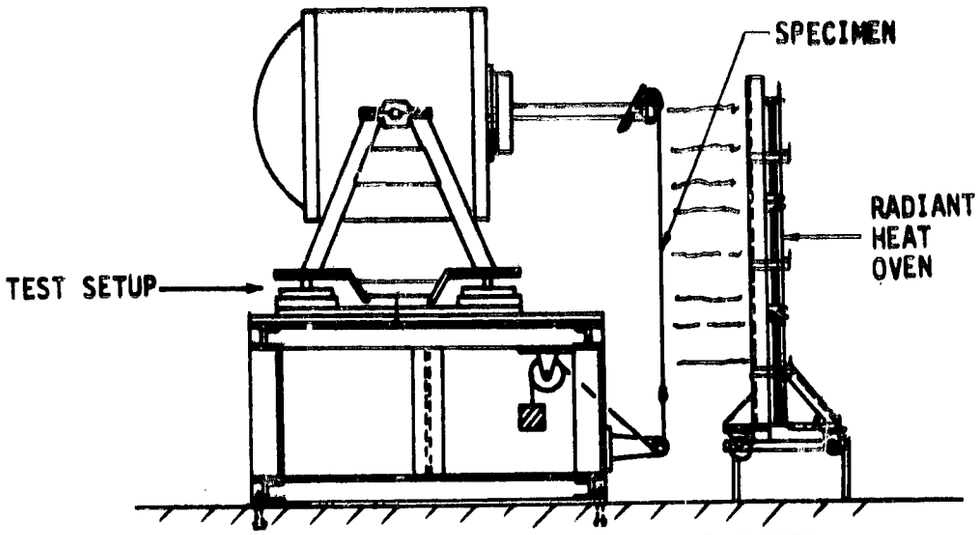
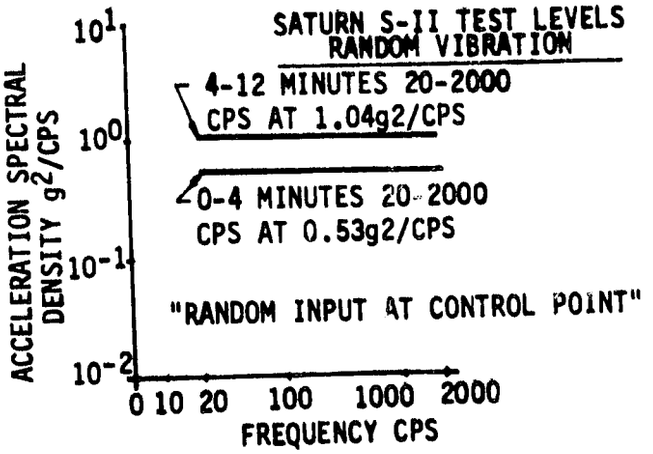
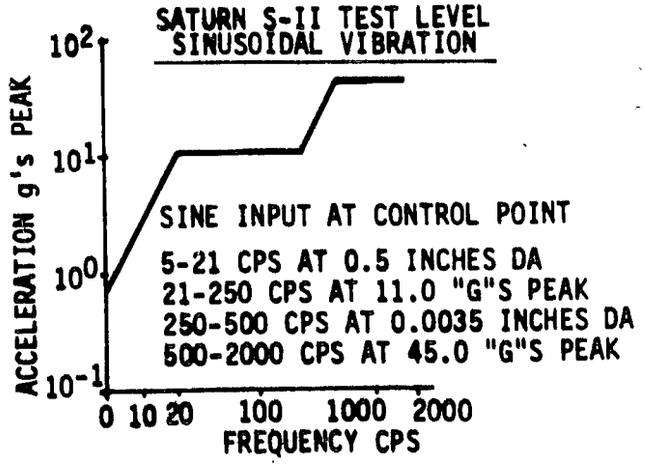
SATURN II FLEX BASE HEAT SHIELD



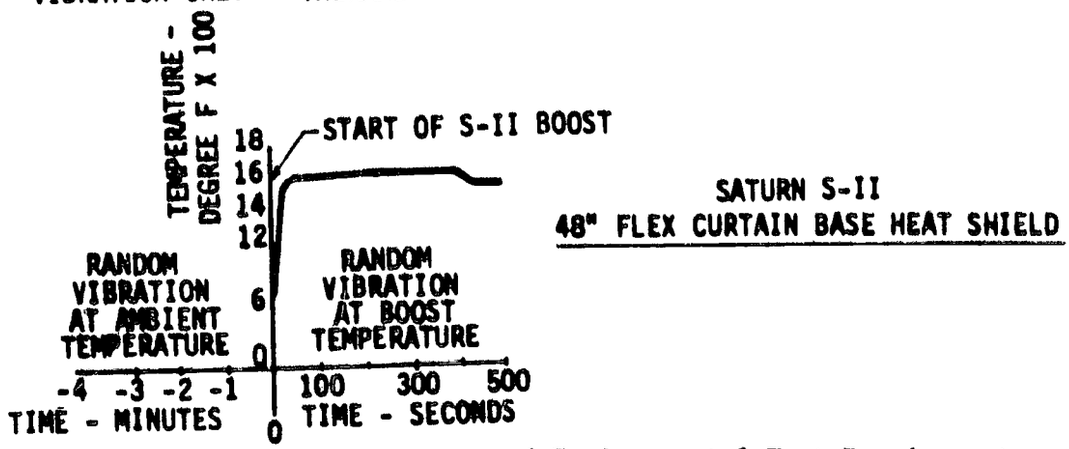
ENVIRONMENTAL TEST REQUIREMENTS

1. SINE SWEEP AT AMBIENT TEMPERATURE. 5-2000-5 CYCLES/SEC AT ONE OCTAVE/MIN
2. RANDOM VIBRATION FOR 4 MINUTES
3. CONTINUE RANDOM IN CONJUNCTION WITH AERODYNAMIC HEATING PROFILE (1650 F MAX) FOR 470 SECONDS





VIBRATION ONLY THERMAL PROFILE



SATURN S-II
48" FLEX CURTAIN BASE HEAT SHIELD

Figure 6.3.4.2-3. Equipment and Environmental Test Requirements

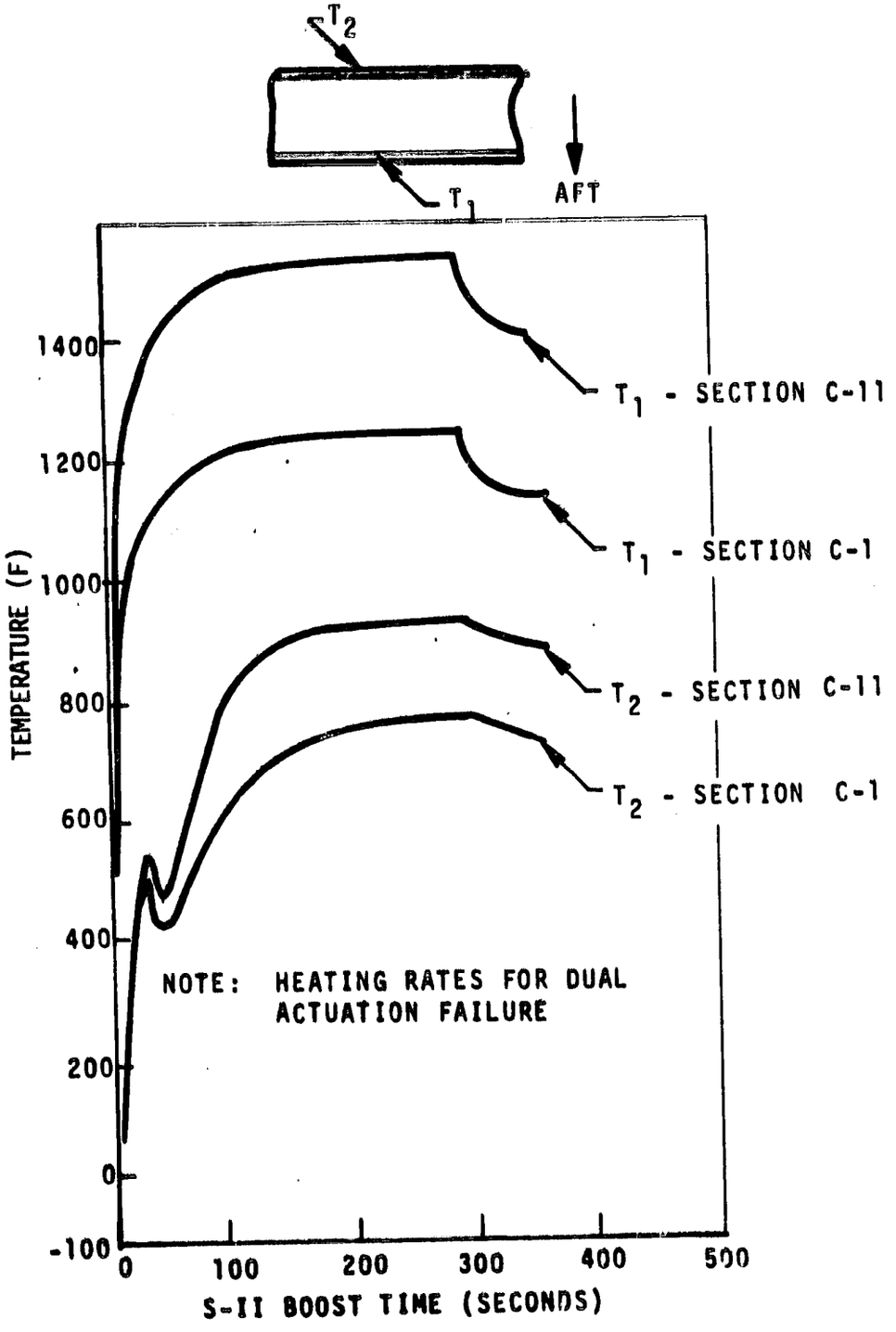


Figure 6.3.4.3-1. Typical Flexible Curtain Sections

6.3.4.4 Structural Performance

Critical loading on the flexible curtain results from pressure (static plus cyclic) and temperature loading. Effects of vibrational loads were considered negligible for the S-II design. Significant factors affecting the strength of the flexible curtain are:

a. Orientation and density (number per inch) of stitching

b. Spacing of the rows of stitching

c. Number of elements sewn together

d. Protection of threads

6.3.4.5 Materials and Processes

a. Materials:

1. High-silica reinforced mat (MB0135-015).

2. High-temperature glass fabric (MB0135-018).

3. Temperature-resistant glass thread (MB0135-022).

b. Processes: Storage, handling, and processing of the materials used to fabricate the flexible curtain are described in Section 11. The curtain is fabricated in accordance with MA0605-002. Patterns of the glass fabric and silica mat are cut in accordance with the applicable engineering drawing. To prevent fraying along the trim line, Kant Fray solution is applied (H.I. Thompson Fiberglass Company, Gardena, Calif.). The splice joints of the mat or fabric are sewn with glass thread using a stitch in accordance with Federal Standard No. 751.

6.3.4.6 Manufacturing

a. Description: Glass fabric and batting sewn together with glass thread constitute the basic structural components of the flexible curtains. Curtain material and batting are cut to developed flat pattern templates, folded over batting, and machine-sewn into small detail assemblies. Larger subassemblies are machine-sewn to template configuration, forming approximately 120 degrees of coverage around the engine and rigid heat shield (Paragraph 6.3.1.6). Glass cloth attach loops are added to provide a means of fastening the curtain to the rigid heat shield and lower attach ring at the engine.

The curtains are fit-checked on the vehicle instead of with a simulated tool. The curtains were altered to fit where required.

Installation of three curtains on the center engine compartment comprises the entire circle of protection. They are tied together along three joints with glass ropes interlaced at presewn loop straps. Four curtains are

attached to the four outboard engines in the same manner. The fabrication and installation sequence is shown in Figure 6.3.4.6-1.

b. Tooling and Equipment: Templates for flat patterns were the only tools used. Equipment items consisted of scissors, knives, sewing machines, standard Rotex punch, and a shipping container.

6.3.4.7 Quality Assurance

The flexible curtain was fabricated without the use of any perishable raw materials. In-process quality control was limited to dimensional and visual inspection during and following production of the insulation details. Final acceptance was accomplished by a fit-check on the vehicle in which the curtain was completely installed and the engines were gimbaled to verify a noninterference fit.

6.3.4.8 Maintenance and Repair

No standard repair or maintenance procedures were developed.

6.3.4.9 Reliability

One mode, fabric tearing, is identified as the means of failure. FMEA results are presented in Table 6.3.4.9-1.

Table 6.3.4.9-1. FMEA—Flexible Heat Shield—Glass Fabric and Batting

Subsystem or Component	Failure Mode	Mission Effects Remarks
Heat Shield	Tearing of Fabric	Overheating of components in thrust structure area

6.3.4.10 Safety

a. Fabrication and Installation: During the fabrication and installation of parts and components of this insulation system, operations must be conducted in accordance with the applicable sections of Industrial Safety Operations Standards.

b. Flexible Heat Shield Use: The flexible heat shield must be installed between the base heat shield and engine bell as late as possible in prelaunch preparations to minimize flexure during checkout of other systems and to reduce the possibility of damage while other work is being done in the engine area.

After installation of the flexible heat shield, the engines must be gimbaled through the operating limits to verify that the curtain has been properly installed and does not restrict engine movement or impose excessive stresses on the curtain.

6.3.4.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the flexible heat shield's relative cost. No data are available on the hours required per square foot.

b. Schedule: No schedule flow times are available.

c. Weight: The total as-installed weight is 0.352 lb/ft^2 broken down as follows:

1. Batting (MB0135-015) - 0.2322 lb/ft^2

2. Fabric (MB0135-018) - 0.1200 lb/ft^2

d. Thermal Performance: Q is not applicable to heat shield evaluation because of the varying heat rates from the engines and the short time span of the heating; ρK is 3.34 $Btu/lb/hr-^oF-ft^4$.

6.3.5 Flexible Heat Shield—High-Silica Fabric and Batting

6.3.5.1 Description

The S-II stages assigned to Skylab missions will experience a thermal environment beyond that which the flexible heat shield material described in Paragraph 6.3.4.1 can withstand. Since the function and configuration of the base heat shield were not changed, the more severe requirements were met by the substitution of materials.

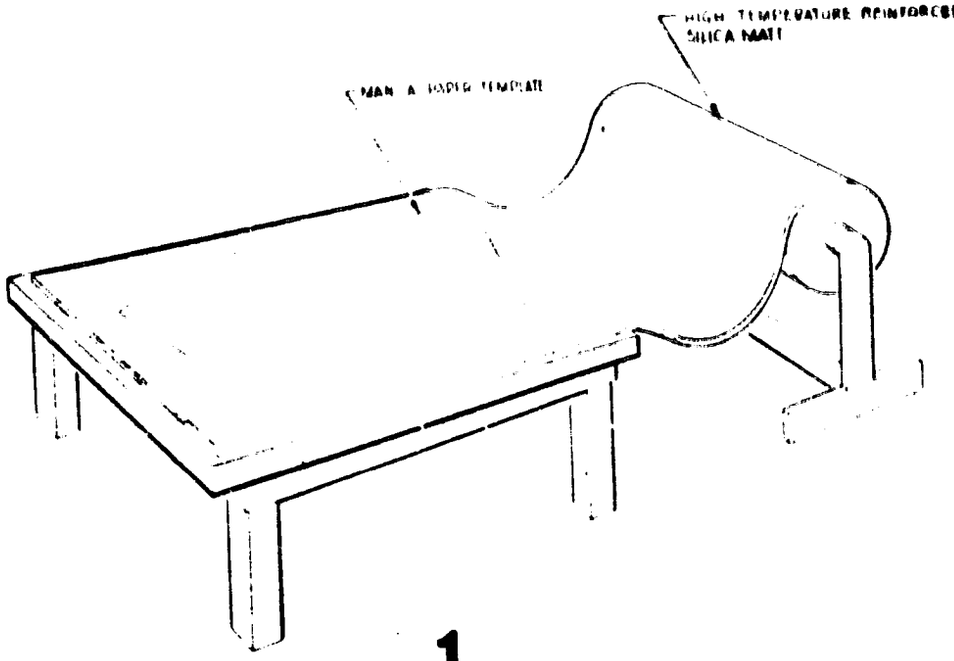
Curtain installation is illustrated in Figure 6.3.4.1-1. A curtain cross section and materials used are shown in Figure 6.3.5.1-1.

6.3.5.2 Application

a. Utilization: This system, incorporating the Irish refrasil fabric, allows the system to be used in higher-temperature environments than can be withstood by the glass fabric system.

b. Performance Characteristics: No real-time data are available with which to assess the performance characteristics of this system.

c. System Limitations: This system is designed to meet the requirements of the Skylab missions, in which temperatures to 2400 F and differential pressure loads of 0.80 psid are predicted for the worst-case conditions.



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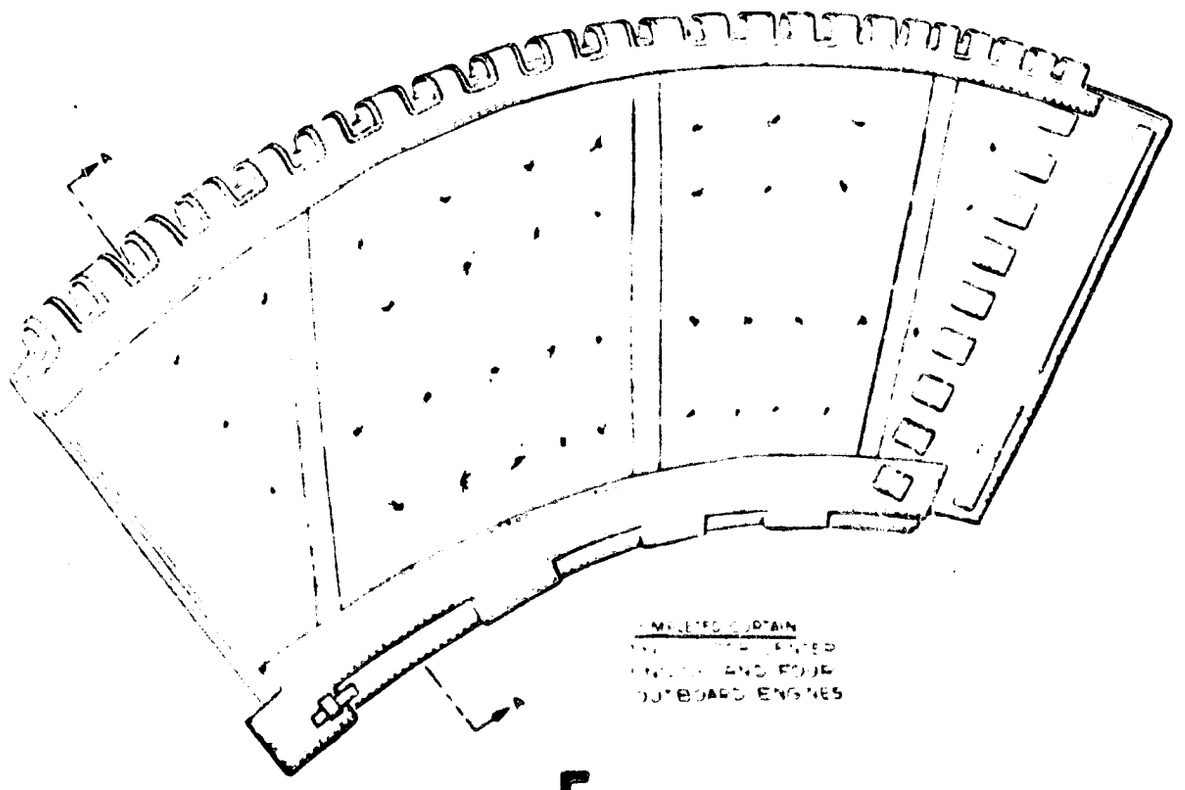

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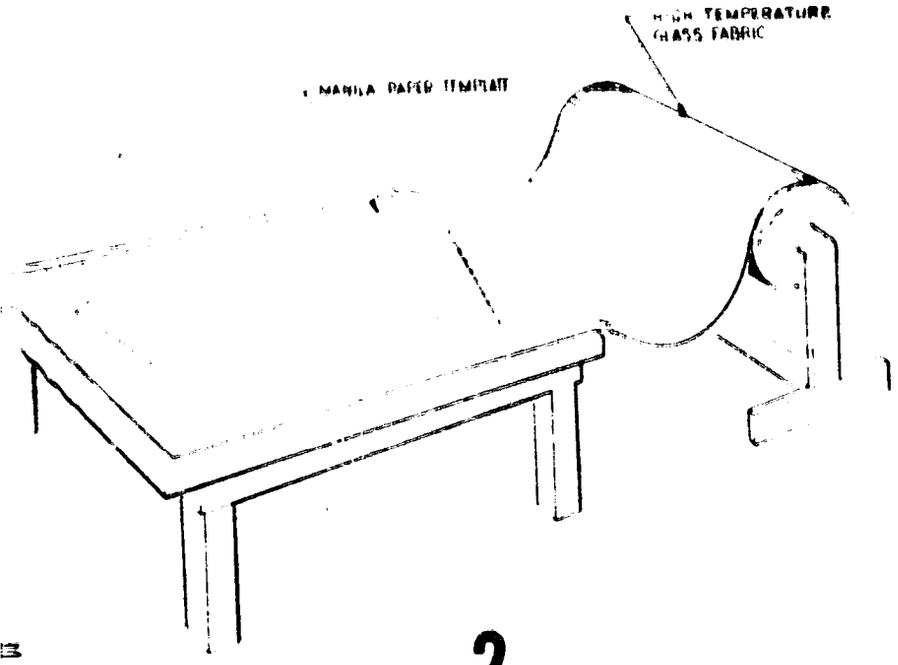
FOLDOUT FRAME



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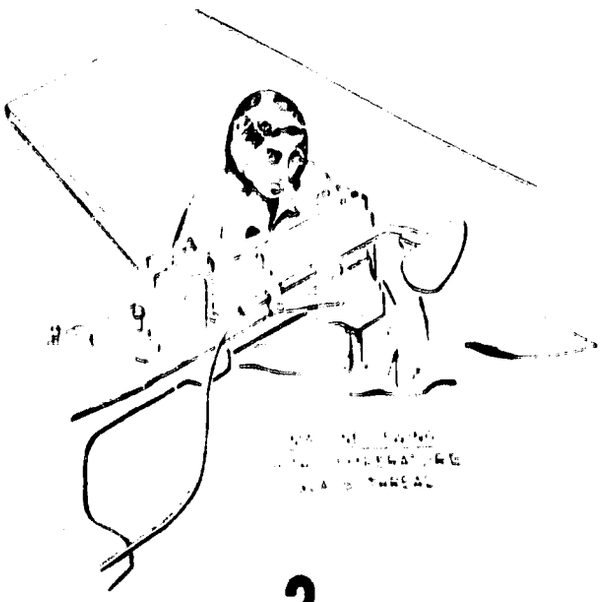

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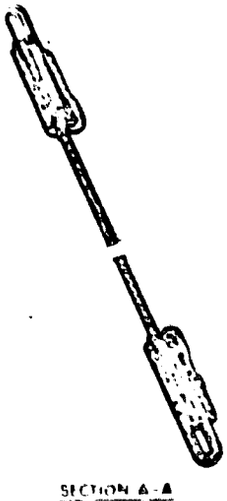
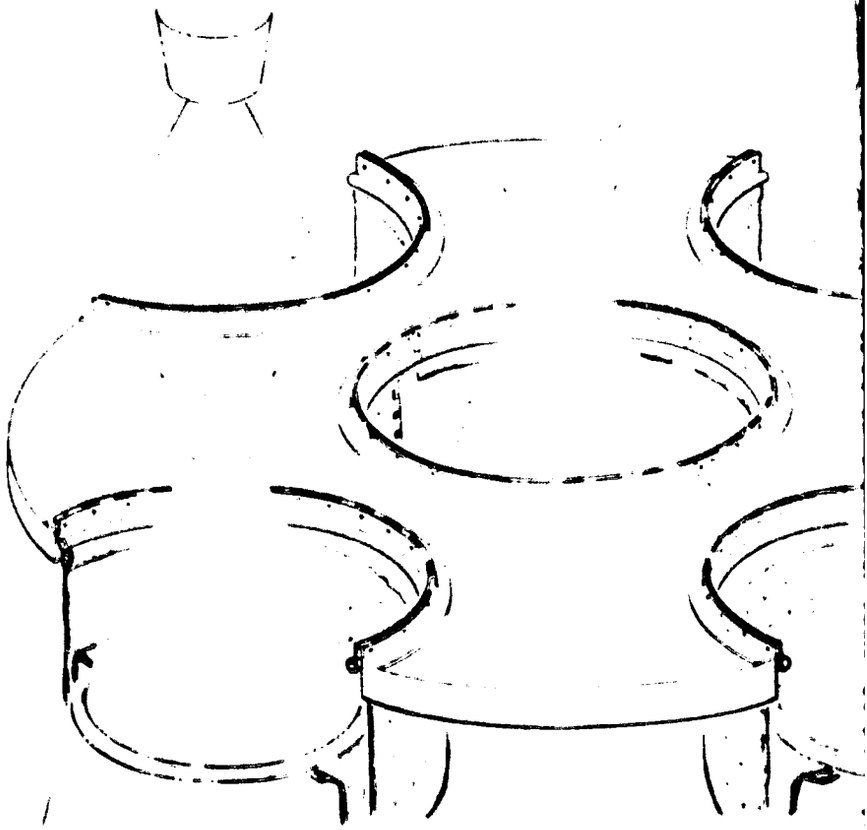


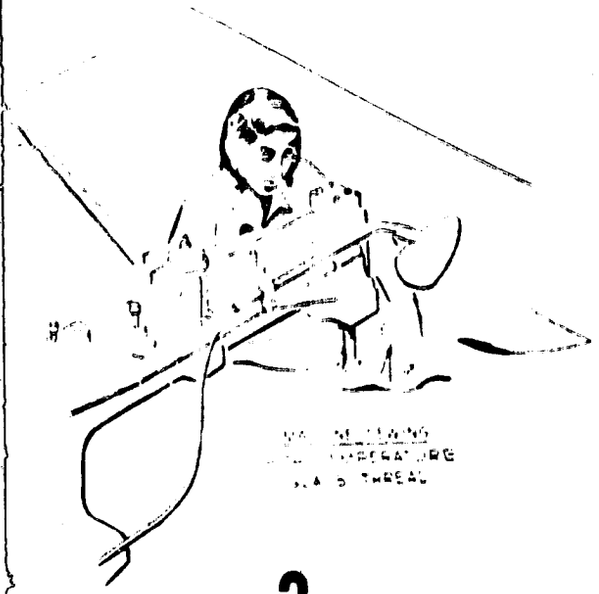
SECTION A-A



TYPICAL GLASS [illegible] INSTALLATION

6

FOLDOUT FRAME 2



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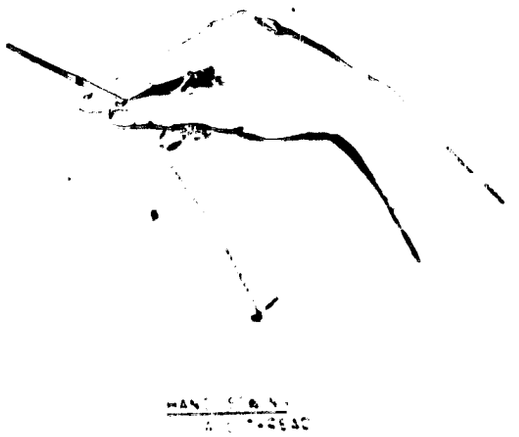

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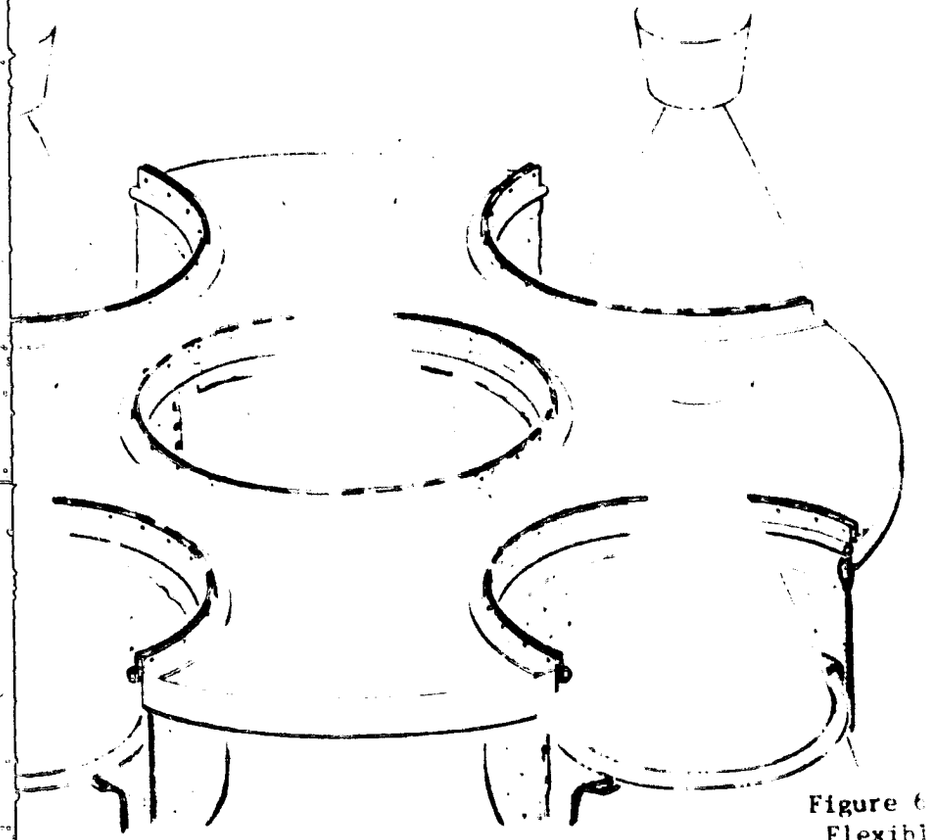

TYPICAL GLASS [illegible] INSTALLATION

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Figure 6.3...6-1. Glass Fabric and Batting Flexible Heat Shield Heat Shield Curtain

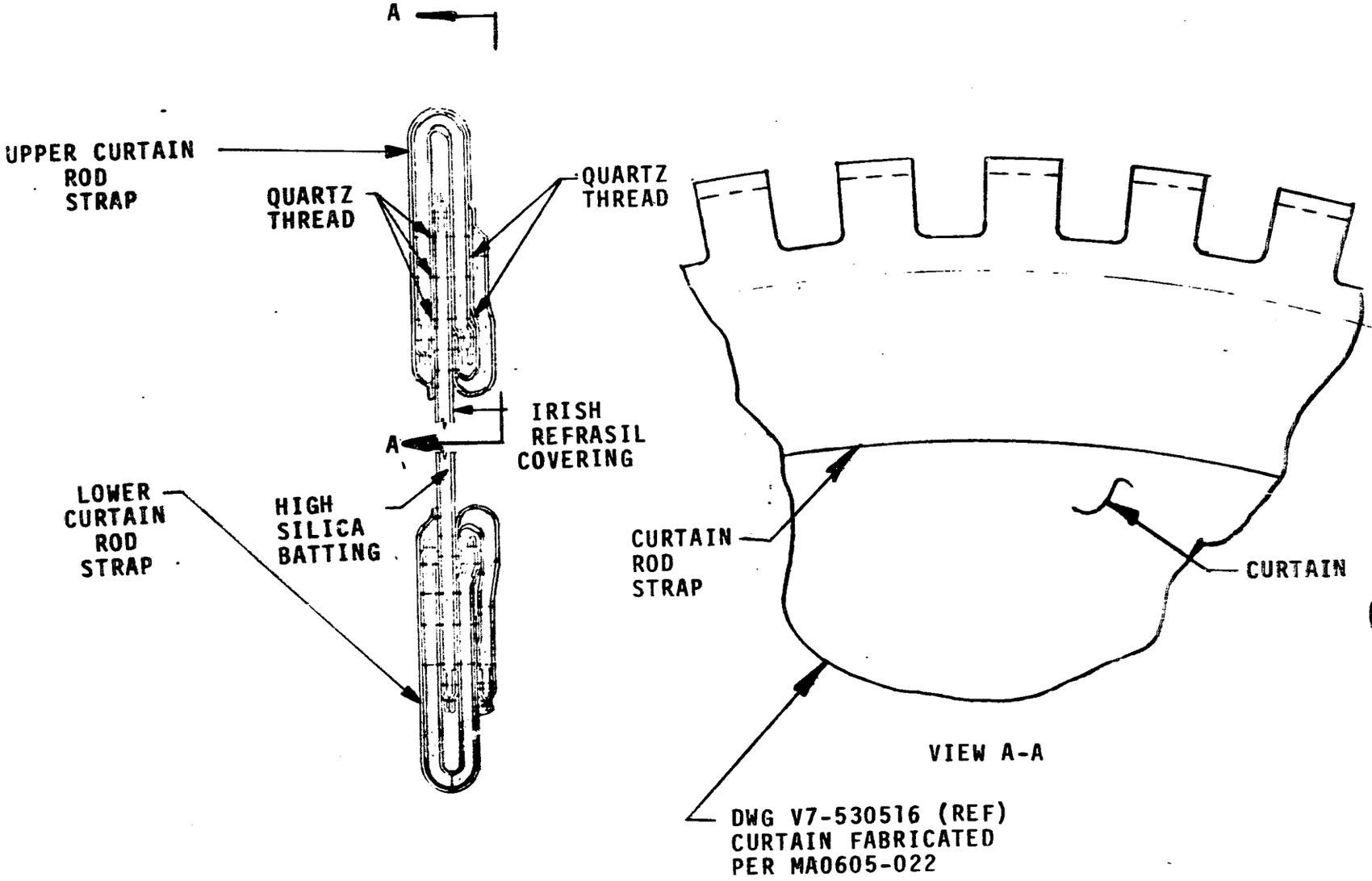

Figure 6.3.5.1-1. Engine Heat Shield Flexible Curtain

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d. Design Problems: The design of this system is relatively simple, and, as with the system described in Paragraph 6.3.4.2, the problems are associated primarily with manufacturing. These problems are as follows:

Problem	Solutions
Quartz threads broke upon direct contact with sewing machine	1. Clear plastic film was placed over curtain to prevent abrasion
	2. Polyethylene film was fused with the fabric (S-II-15)
Resewing previously sewn areas resulted in damage to cloth and threads	Sewing was restricted to virgin areas

e. Verification Tests: Verification testing of the system is described in SD 72-SA-0027. Data from both tensile and fatigue tests on fill and warp specimens demonstrated the ability of the flexible curtain to withstand temperatures to 2400 F and pressure loads up to 34 pounds per inch (0.80 psid).

6.3.5.3 Thermal Performance

An important performance requirement of the flexible curtain design for the Skylab mission is that it be capable of withstanding the temperature distributions caused by the predicted heating rates. The predicted maximum convective heating rates on the flexible curtains for the center and outboard engines were 7.7 Btu/ft^2-sec and 13.3 Btu/ft^2-sec, respectively. Based on these rates, maximum temperatures attained were 1520 F and 1760 F for the center and outboard engine flexible curtains, respectively.

6.3.5.4 Structural Performance

Structural prime drivers in the proper design of the flexible heat shield (refrasil and batting) are identical to those given for the basic S-II design (glass fabric and batting) in Paragraph 6.3.4.4.

6.3.5.5 Materials and Processes

a. Materials:

1. Fabric:

(a) High-silica reinforced mat (MB0135-015).

(b) Amorphous silica, chromium-treated, polytetrafluorethylene-coated fabric (MB0135-028).

(c) Temperature-resistant quartz thread, polytetrafluorethylene-coated (MB0135-029).

(d) High-silica braided rope (MB0135-030).

(e) Electrical-insulating, shrinkable Teflon sleeving (MB0150-025).

b. Processes: The temperature-resistant flexible curtains were processed in accordance with MA0605-022.

1. Trimming: The mat and fabric are trimmed to the configuration of the engineering drawing, with special attention given the fabric warp direction designated on the drawing.

2. Sewing: The section or panels are sewn together with quartz thread using a stitch that conforms to Federal Standard No. 751. Interrupted stitching that results from a broken thread is restarted 3/4 inch to 1-1/2 inches before the broken thread.

3. Lacing Ropes: The rope and sleeve are cut to length, with the sleeve extending 1/16 to 1/8 inch beyond the cut end of the rope and installed in accordance with STO 105CA0001. The exposed rope is then sprayed with three coats of MS-122 release agent (Miller Stevenson Chemical Company, Inc., Los Angeles, Calif.) or equivalent.

6.3.5.6 Manufacturing

a. Description: Sewing operations are the same as those described in Paragraph 6.3.4.6, except that materials are high-silica fabric (refrasil) and quartz thread.

b. Tooling and Equipment: Refer to Paragraph 6.3.4.6.

6.3.5.7 Quality Assurance

The quality control procedures were as stated in Paragraph 6.3.4.7.

6.3.5.8 Repair and Maintenance

a. Repair: Repairs to the flexible curtain are made in accordance with MA0605-024 or by engineering direction. In both cases, the repair requires Material Review Board approval.

b. Maintenance: To prevent damage to the flexible curtain, the part must be stored in a manner that will prevent folding or creasing of the coated fabric.

6.3.5.9 Reliability

The basic mode of failure is tearing of fabric. FMEA results are presented in Table 6.3.5.9-1.

Table 6.3.5.9-1. FMEA—High-Silica Fabric and Batting

Subsystem or Component	Failure Mode	Mission Effects Remarks
Heat Shield	Tearing of Fabric	Overheating of components in thrust structure area

6.3.5.10 Safety

No hazard analyses have been conducted, and insufficient operational experience has been accumulated on this insulation system to formulate safety requirements.

6.3.5.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the flexible heat shield's relative cost: 15 hours per square foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 10 weeks.

Subassembly - 16 weeks.

Installation - 1 week.

Checkout - 1 week.

c. Weight: The total as-installed weight is 0.517 lb/ft^2 broken down as follows:

1. Batting (MB0135-015) - 0.232 lb/ft^2
2. Fabric (MB0135-028 Type II) - 0.284 lb/ft^2

d. Thermal Performance: Q is not applicable to heat shield evaluation because of the varying heat rates from the engine and the short time span of the heating; PK is 4.91 $Btu/lb/hr-^oF-ft^4$.

6.3.6 Bonded Cork Sheet

6.3.6.1 Description

The bonded-cork insulation system is used to protect the exterior surfaces of the S-II interstage and aft skirt structures from aerodynamic heating during boost (V7-531320 and V7-315007). The bonded cork provides a heat sink and an

ablative surface that prevents the substrate structure temperature from exceeding the permissible upper limit.

The concept consists of bonding prefit cork sheet details to the exterior surfaces of the structures (skins and stringers) that are to be protected. In areas where the structural detail is complex in shape, the cork is applied either in segmented strips or in preformed shapes. This insulation concept is shown in Figure 6.3.6.1-1.

6.3.6.2 Application

a. Utilization: Cork is bonded to the surface of the S-II tank structure to protect the structure from excessive temperatures during boost. This is one of the many space applications of cork over metal to provide thermal protection. Cork has been used on nose cones and leading edges and for thermal control of instrumentation components.

b. Performance Characteristics: The cork-bonded system has been used successfully on the exterior surfaces of the interstage and aft skirt on S-II-1 to S-II-13 and on the interior surfaces of the aft skirt on S-II-1 to S-II-3.

c. System Limitations: This system was developed to meet the requirements of the S-II program, as discussed in Section 5. The system maintains the temperature on the aft skirt structure at a maximum of 235 F during S-II boost and that on the interstage structure at 500 F during the first 30 seconds of S-II boost.

d. Design Problems: The system consists of a number of preformed and precut cork details bonded to the structure. The principal problems are associated with voids between the cork and the substrate. During the initial installation, many voids in the bond line were encountered using Epon 934 adhesive. Variation in stringer dimensions contributed to this. Change to a contact adhesive (MIL-A-24179) reduced the number of voids.

e. Verification Tests: A verification test program (SID 66-1468) was conducted that included aeroshear, aeroheating, installation verification tests, and environmental exposure tests. A typical specimen and profile for the aeroshear and aeroheat tests are shown in Figures 6.3.6.2-1 and 6.3.6.2-2, respectively.

6.3.6.3 Thermal Performance

Cork bonded directly to structure as protection against aerodynamic, solar, or base heating has unique thermal performance capabilities. It is unique in that it serves to limit the temperature of the structure to which it is bonded by acting simultaneously as an ablator, a heat sink, and conductive insulation.

Cork of varied thickness is employed on the S-II aft skirt and interstage structure to limit the temperature in these areas to allowable structural limits. These structures are exposed to aerodynamic and solar heating during S-IC/S-II boost. Interstage structures are additionally exposed to base

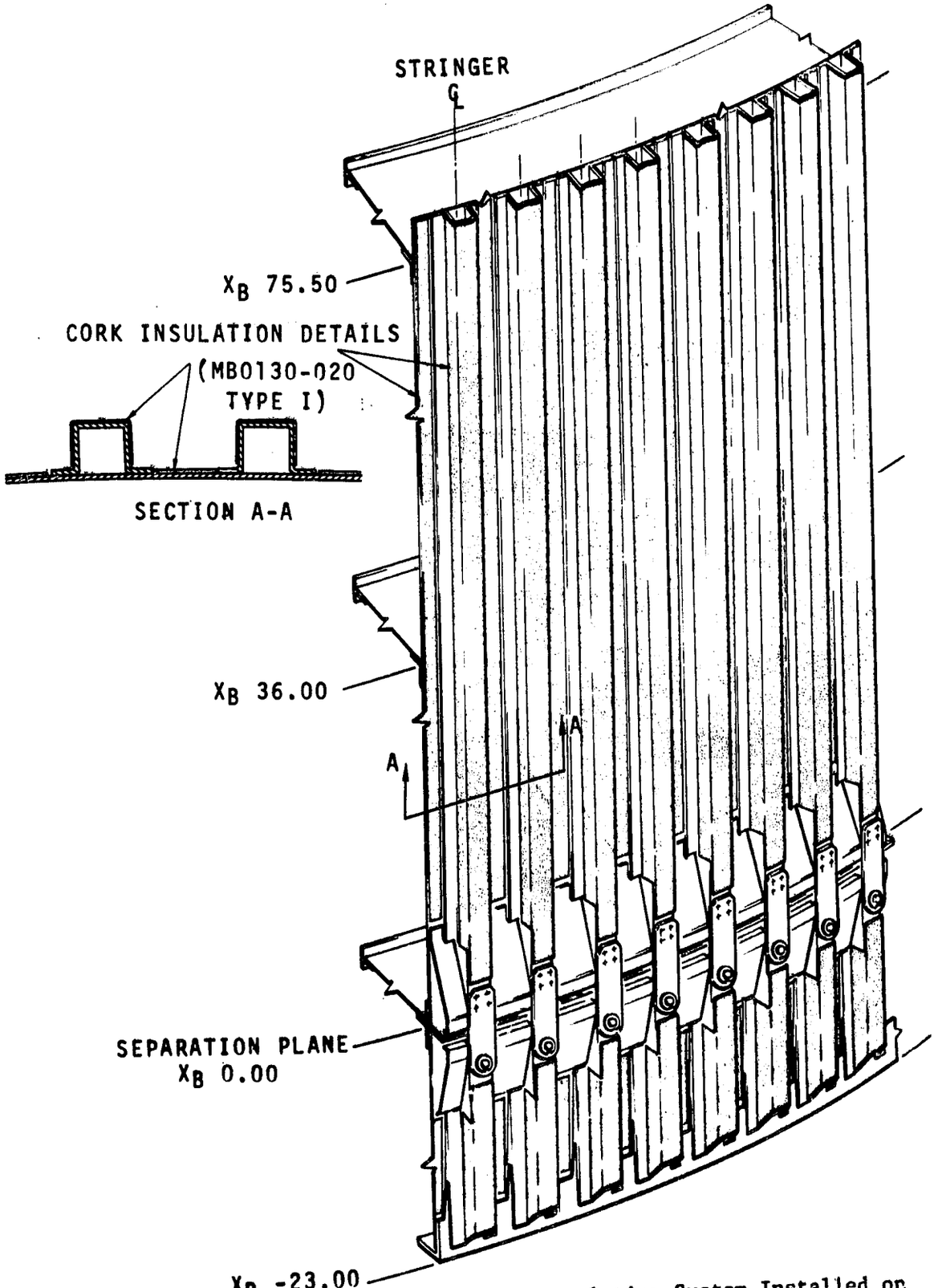


Figure 6.3.6.1-1. Schematic of Cork Insulation System Installed on Interstage Structure

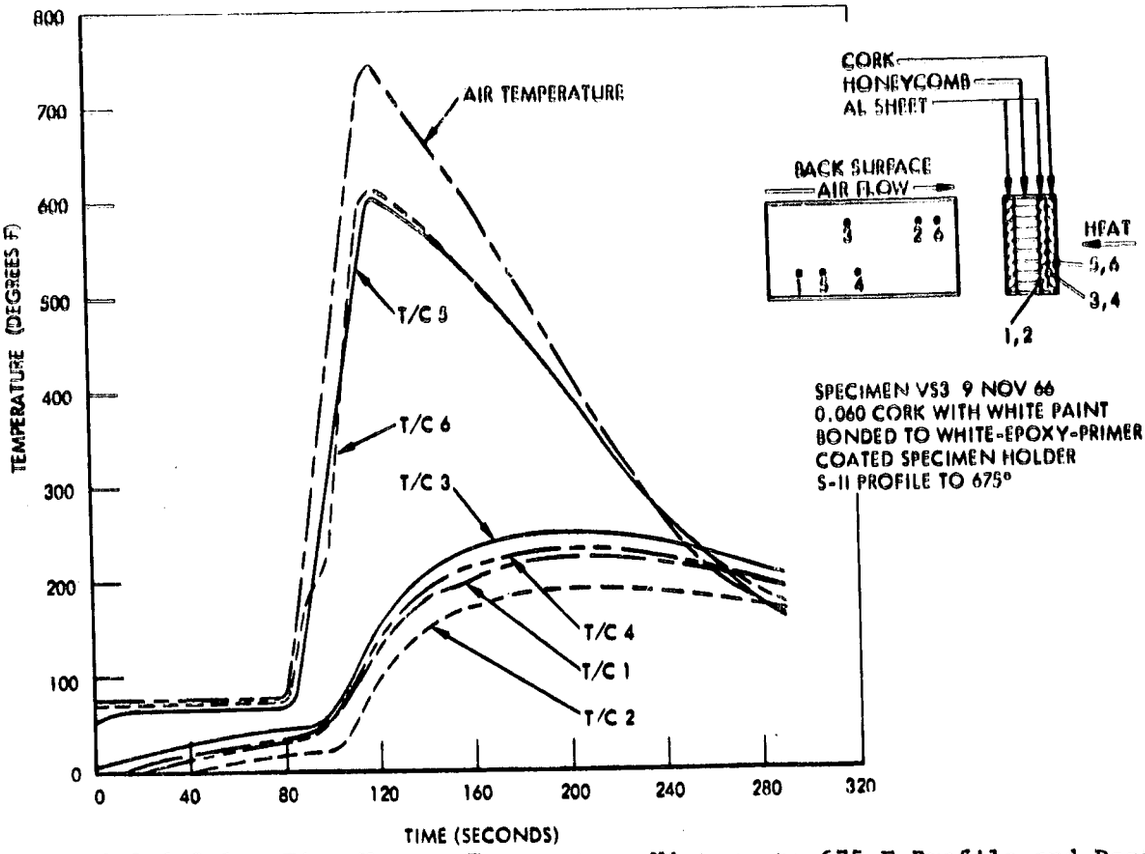


Figure 6.3.6.2-1. Time Versus Temperature History to 675 F Profile and Design Verification Specimen VS3 After Test

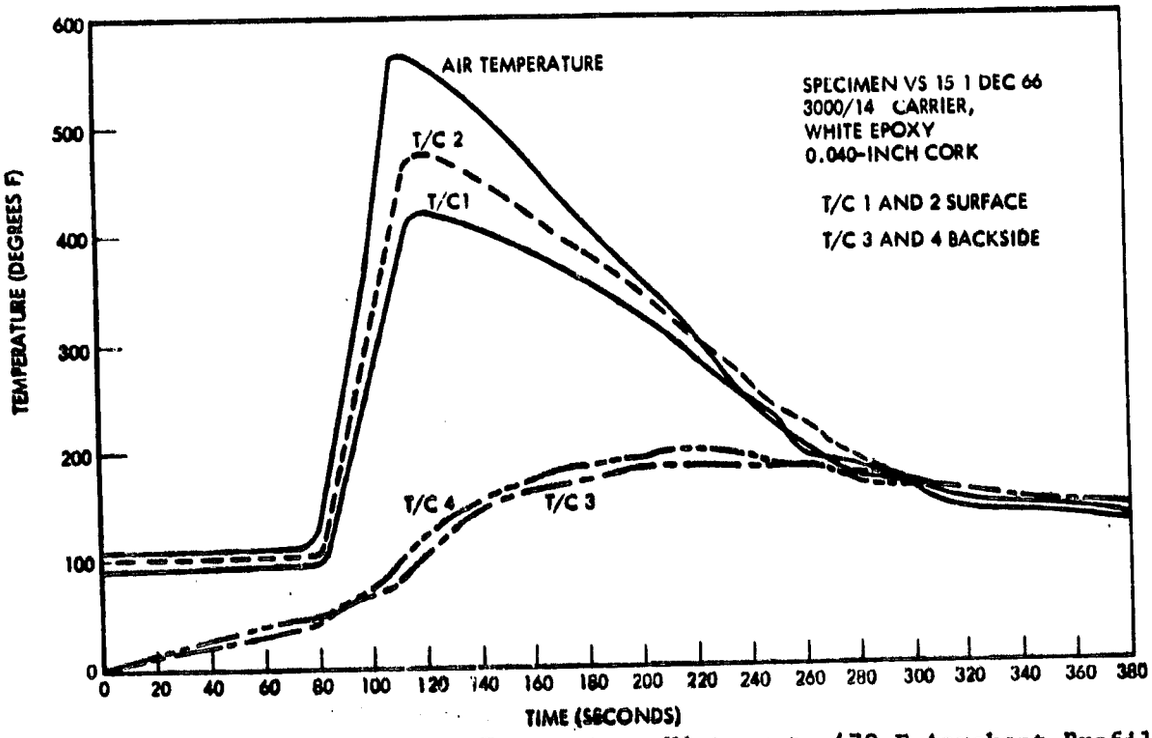


Figure 6.3.6.2-2. Time Versus Temperature History to 470 F Aeroheat Profile and Design Verification Specimen VS15 After Test

heating during the first 30 seconds of S-II boost. Established structural temperature limits for S-II-4 through S-II-15 are 235 F during S-IC boost and 500 F for the interstage during the first 30 seconds of S-II boost.

Assumed aerodynamic heating rates were based on real gas effects for the design heating rate boost trajectory. The effect of protuberances were also considered. Solar heating was assumed to be 438 Btu/hr-^{o}F-ft^{2}. A portion of the aft interstage is subjected to base heating throughout S-II boost. The aerodynamic heating and protuberance effects assumed are as specified in the CEI specification (CP621M0014A). Base heating rates assumed are those defined in SID 61-473-1, S-II Environmental Data for S-II Stage. Material properties assumed for the 30 lb/ft^{3} cork employed are as follows: thermal conductivity equal to 0.05 Btu/hr-^{o}F-ft; specific heat equal to 0.5 Btu/lb-^{o}F; emissivity equal to 0.8; absorptivity = 0.8; initial temperatures (at beginning of S-IC boost) of 0 F between stations 240 and 283 and 80 F between stations -23 and 240.

These data were used in a thermal analysis digital computer program to determine the transient temperature response of the structure due to the externally applied environments. The variation in cork thickness with station and the detailed results of this analysis are presented in Paragraph 7.3.6.1. The maximum aft skirt and interstage structure temperatures of S-II-4 through S-II-15 were calculated to be 235 F or less at S-IC end boost and 460 F or less during the first 30 seconds of S-II boost, indicating that the variations in cork thickness employed in this insulation concept are adequate to limit the structural temperatures as required.

Bonded-cork insulation was also used on S-II-6 and subsequent vehicles to protect the thrust cone web structure located at Station 196. The 196 web is subjected to base heating throughout S-II boost. Further thermal performance details of this application are contained in Paragraph 6.3.7.3.

6.3.6.4 Structural Performance

Significant factors affecting the structural integrity of this insulation system are identical to those given for the cork insulation system in Paragraph 6.1.8.4.

6.3.6.5 Materials and Processes

a. Materials:

1. Adhesive:

(a) Contact (Mil-A-24179 Type I)

(b) Epoxy adhesive system (MB0120-008).

2. Coating: synthetic elastomer (MB0125-036).

3. Insulation: cork sheet (MB0130-020 Type I).

b. Processes: The insulation system is installed in accordance with MA0606-053.

1. Material Storage and Handling: All materials are stored and handled in accordance with applicable material specifications.

2. Cleaning: Prebond cleaning of faying surfaces is done by wiping with solvent in accordance with MA0606-053.

3. Preparation of Cork Insulation: Simple cork insulation details are trimmed from cork sheet. When required by the engineering drawing, the cork is preformed by placing the cork sheet on a preformed tool, raising the cork temperature to 310 ± 10 F, and applying 10(+5, -0) psi pressure to the cork for 10 to 20 minutes.

4. Application of Cork Insulation: Mil-A-24179 Type I adhesive is thoroughly stirred and two brush coats of adhesive are applied to the faying surfaces of both the cork and the structure. The adhesive is air-dried at least 30 minutes between coats and from 60 to 150 minutes between application of the second coat and installation of the cork detail. Since repositioning of the cork detail is not possible after contact of the faying surfaces is made, the structure is covered with a Kraft paper peel sheet, which is peeled back after initial control is obtained at one edge of the detail. The cork insulation is pressed into contact with the structure with a roller or other suitable rub-out paddle. MB0120-008 adhesive, mixed in accordance with the manufacturer's instructions, is used to fill gaps between abutting cork details and to fair the leading and trailing edges of the cork details into the structure.

5. Application of Fungus-Resistant Coating: The cork insulation bond is allowed to cure for 168 hours before the fungus-resistant coating is applied. MB0125-036 material is thoroughly mixed and applied to the exposed surfaces of the cork insulation in accordance with MA0606-053. Two or three coats of MB0125-036 material are applied by brush or spray to obtain approximately 5 mils of thickness. The material is allowed to air-dry 30 minutes between coats and at least 12 hours after the final coat is applied.

6.3.6.6 Manufacturing

a. Description: Sheet cork and molded cork are bonded to the S-II interstage and aft skirt structures in a manner similar to the sequences outlined in Paragraph 6.1.8.6. The hat-shaped stringers are covered with cork in two ways: (1) by knife-cutting cork from sheets using a straight edge as a guide; (2) by preforming the developed flat pattern cork in a preform tool using heat and vacuum bag pressure.

Contact adhesive is applied to the sides of the stringers and tank wall surfaces and to the faying surfaces of the cork. The cork is then positioned to the prefit location on the stringer. Contact pressure is applied with hand rollers. After cure, excess adhesive is removed by filing and

sanding in preparation for brush or spray coating with color-pigmented fungus-resistant paint. The manufacturing sequence of operations is illustrated in Figure 6.3.6.6-1.

b. Tooling and Equipment: Similar to that described in Paragraph 6.1.8.6.

6.3.6.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0606-053):

1. General: The cork was bonded to the structure with a solvent-based contact adhesive, MIL-A-24179, and all joints subsequently sealed with an epoxy adhesive, MB0120-008. Routine controls were invoked relative to cleaning of the painted structure, environmental control, adhesive mix verification, and open assembly time.

2. Process Verification Coupons: A process verification coupon was required to be fabricated with each production operation involving the MIL-A-24179 adhesive. The coupon consisted of four 2-inch by 10-inch sections of sheet cork bonded to a painted aluminum sheet representative of the production structural surfaces being insulated. The test coupon was subsequently sent to the laboratory for assessment of bond integrity.

c. Quality Verification of Final Assembly: As a final production operation, all cork surfaces were painted with a fungus-resistant coating (MB0125-036). The insulated structure was inspected before and after coating, as follows:

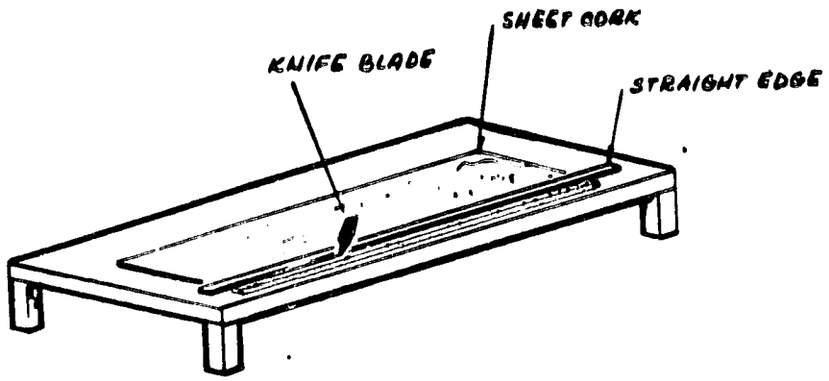
1. Precoating Visual Inspection: Bonded cork details were visually inspected to the following requirements extracted from MA0606-053:

(a) Bonded cork details shall be free of cracks other than surface cracks around sharp radii caused by forming operations.

(b) Individual bondline voids shall not exceed one inch in the smallest dimension.

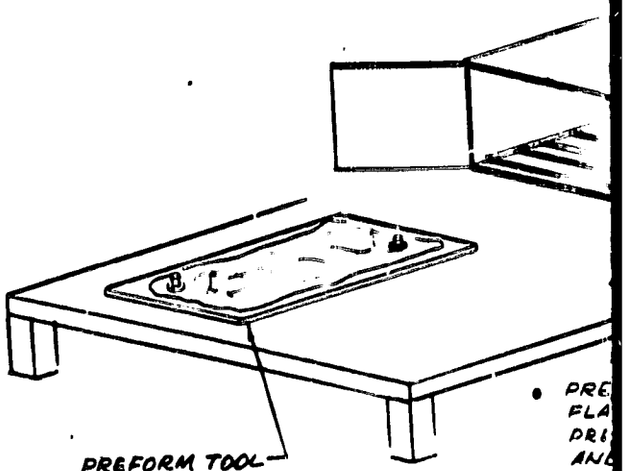
(c) Individual bondline voids shall not exceed 10 square inches in area. Voids separated by one quarter inch or less shall be considered as one void when calculating allowable void areas.

(d) No voids shall be permitted within one inch from the leading or trailing edges or one quarter inch from any side of a bonded cork detail.



KNIFE CUT CORK USING STRAIGHT EDGE AS A GUIDE

1



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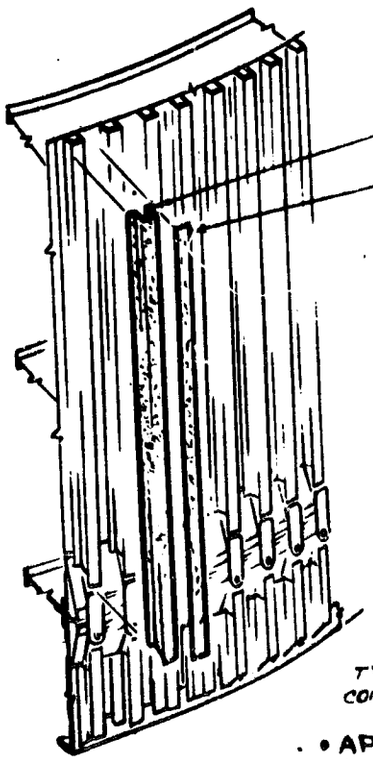
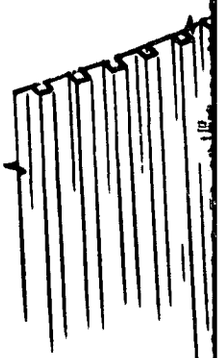
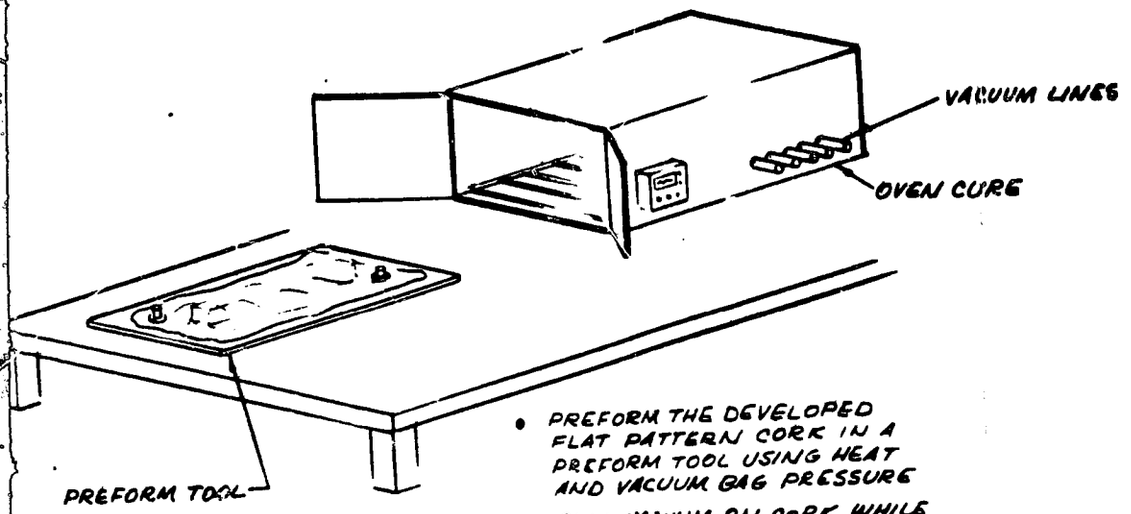




TYPICAL INSTALLATION OF CORK INSULATION SYSTEM

- APPLY ADHESIVE TO SHEET STRIP CORK
- APPLY ADHESIVE TO "U" CHANNEL CORK
- APPLY ADHESIVE TO STRINGERS
- ROLL CORK WITH ROLLER
- CURE

FOLDOUT FRAME

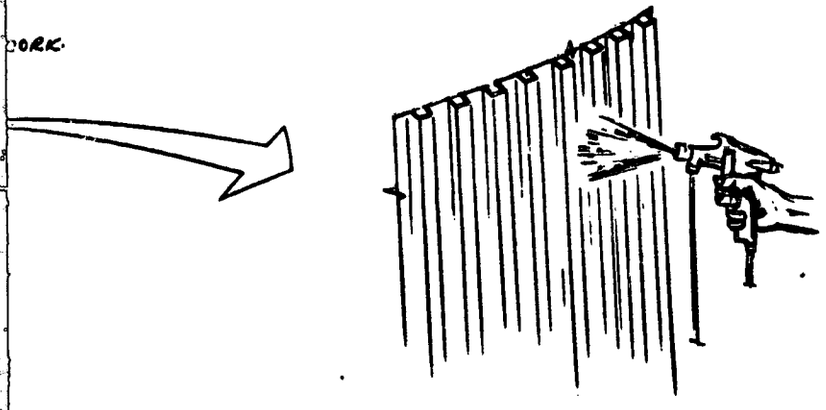


2

- PREFORM THE DEVELOPED FLAT PATTERN CORK IN A PREFORM TOOL USING HEAT AND VACUUM BAG PRESSURE
- PULL VACUUM ON CORK WHILE HEATING THEN COOL SLOWLY

ORK

ORK



- APPLY FUNGUS APPLICATION SPRAY
- APPLY COLOR COAT SPRAY

4

TION OF
YSTEM

E TO SHEET STRIP CORK
TO "U" CHANNEL CORK
TO STRINGERS
H ROLLER

Figure 6.3.6.6-1. Cork-Bonded Insulation

FOLDOUT FRAME 2

2. Post-Coating Visual Inspection: During application of the insulation system to initial Saturn S-II vehicles, it was learned that visual inspection of the cork was extremely difficult because of the texture of the unpainted cork surfaces. Some unacceptable void areas were found after application of the fungus-resistant coating when light reflection aided the inspector. For that reason the visual inspection noted above was repeated following application of the final top coat.

6.3.6.8 Repair and Maintenance

Although in-process rework of cracks and voids are allowed in MA0606-053, all discrepancies discovered subsequent to completion of the installation were repaired in accordance with Material Review Board dispositions. No special maintenance of this insulation system is required by the engineering drawing or specification.

6.3.6.9 Reliability

There was no detailed failure mode effects analysis formulated because of the absence of any obvious first-order failure modes.

6.3.6.10 Safety

a. Fabrication and Installation: Careful fitting of the insulation detail parts is necessary to ensure the integrity of the assembly. Many interfaces are present that would lead to the loss of a positive protection if these interfaces are not sealed by fitting the parts to eliminate large gaps or voids.

   During the assembly of this system, it is necessary to ensure that errors of installation are not covered by later installations. In-process inspection and testing must be used to verify that each portion of the system is sound prior to the installation of the next part. Additional safety requirements are given in Paragraph 6.1.1.10.

b. Cork Insulation Use: Cork insulation is a passive system and no special precautions—other than surface protection, regular inspection, and repair—are necessary during its use.

6.3.6.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. No data are available on the required hours per foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 10 weeks.

Subassembly - 0.

Installation - 9 weeks.

Checkout - 0.

c. Weight: The total as-installed weight is 0.184 lb/ft^2 broken down as follows:

1. Cork, 0.062-inch thick (MB0130-020) - 0.160 lb/ft^2

2. Adhesive (MIL-A-24179) - 0.024 lb/ft^2

d. Thermal Performance: Q is not applicable to this insulation system as used on S-II because of the varying heat rates; ρK is 1.57 $Btu/lb/hr-{}^oF-ft^4$.

6.3.7 RTV Silicone Rubber Coating

6.3.7.1 Description

Silicone rubber insulation material was used on S-II-1 through S-II-5 to protect the structural frame at Station 196 from convective and radiant base heating during S-II boost (V7-315005). The relatively low thermal conductivity of a room-temperature-vulcanizing (RTV) silicone rubber compound, along with its heat capacity, provided the thermal resistance required to lower the maximum temperature of the structure to acceptable levels.

A coating of RTV silicone rubber compound was applied to the aft side of the frame structure, as shown in Figures 6.3.7.1-1 and 6.3.7.1-2. On S-II-6 and subsequent vehicles this design was replaced with a bonded-on cork concept at a considerable weight savings. Details of the cork design are also shown on V7-315005.

6.3.7.2 Application

a. Utilization: This application uses ambient-temperature-curing silicone rubber compound as an ablative coating to limit temperature in critical structural areas.

b. Performance Characteristics: The system was installed on the first five S-II stages. No specific tests were conducted to establish the performance characteristics. There were no indications of failure during flight, as demonstrated by successful completion of the mission objectives.

c. System Limitations: The system is designed to perform within the stage design limits. These limits state that the silicone system must limit the 196 web to 500 F at the end of 30 seconds of S-II boost. Tests in the

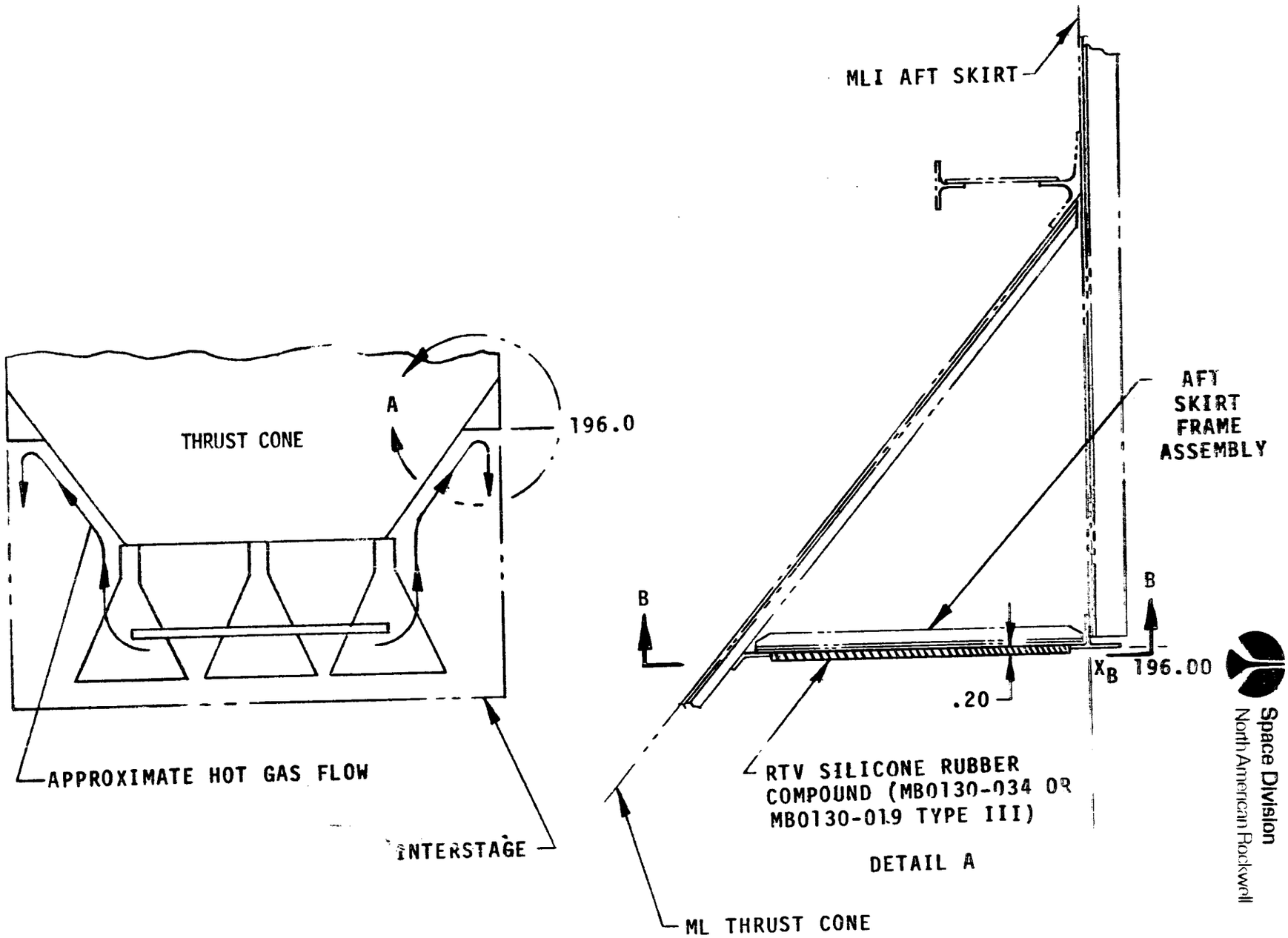
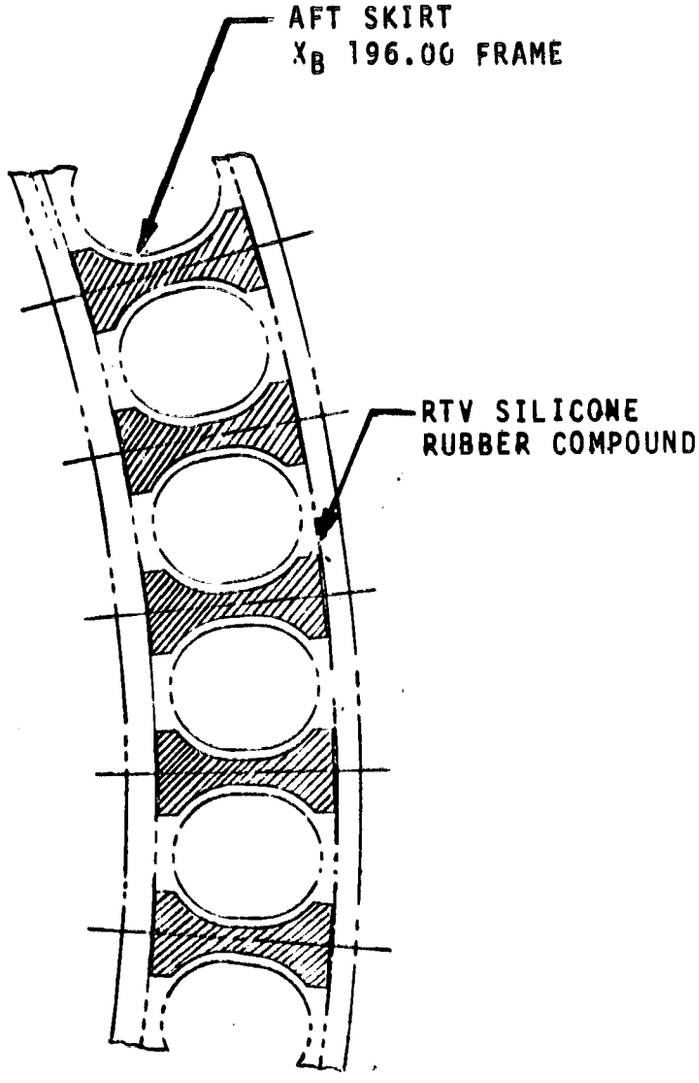


Figure 6.3.7.1-1. RTV Silicone Rubber Coating

Space Division
North American Rockwell



VIEW B-B

Figure 6.3.7.1-2. RTV Silicone Rubber Coating

laboratory indicated that the system would limit the temperature to 450 F. Data indicate the material is good for continuous use to 450 F.

d. Design Problems: No specific design problems were encountered. The difficulty of installing the system to a given thickness led to using bonded cork on the web to facilitate application.

e. Verification Tests: Verification was made by using small laboratory test specimens to demonstrate the application and ability to adhere to the substrate. Verification was further obtained as the result of S-II stage cryogenic tests, which indicated no failures of the system.

6.3.7.3 Thermal Performance

The S-II thrust cone web section located at Station 196 is subjected to convective and radiant base heating throughout S-II boost. The base heating rates are as specified in SID 61-973-1. The heating rates vary, however, both with angular position due to clustered engine effects and with boost time as a function of interstage presence (off after 30 seconds) and engine mixture ratio (which is reduced after 350 seconds of S-II boost). Without insulation protection, the temperature of the 196 web was found (by analysis) to exceed the allowable strength-limiting value.

To provide the required thermal protection on S-II-1 through S-II-5, the 196 web structure was coated with 1/4-inch-thick RTV insulation. S-II-6 and subsequent vehicles were insulated with 1/4-inch-thick bonded cork (a lighter-weight material). The RTV has a density of 80 lb/ft^3, a thermal conductivity of 0.12 $Btu\text{-}ft/ft^2\text{-}Hr\text{-}^oF$, and a specific heat of 0.3 $Btu/lb\text{-}^oF$.

A thermal analysis of this insulation concept indicated that the maximum uninsulated temperature of the 196 web (720 F) was reduced to 450 F by use of 1/4-inch-thick RTV insulation. Use of 1/4-inch-thick bonded cork (30 lb/ft^3) (the system employed on S-II-6 and later vehicles) reduced the maximum 196 web temperature to 480 F, which is within allowable limits and results in a weight savings of approximately 60 percent.

6.3.7.4 Structural Performance

A significant factor affecting the structural integrity of this insulation system is the difference in thermal contraction and expansion rates between the base structure and the ablative coating. These must be determined in order to determine the stress levels developed in the coating. A discussion of the structural analysis of organic materials is contained in Section 8.0.

6.3.7.5 Materials and Processes

a. Materials:

1. Silicone: RTV paste (MB0130-034).

2. Primer: room-temperature silicone (AB0125-007).

b. Processes: The RTV rubber coating is applied to the aft skirt (Figure 6.3.7.1-1) in accordance with MA0106-055.

1. Surface Preparation: All surfaces to be primed are prepared in accordance with MA0110-023.

2. Application of Primer: The primer is applied to a clean surface by brushing, dipping, or spraying. (The surface, after priming, is a uniform translucent pink color. A dark pink indicates too much primer, while an almost colorless pink indicates insufficient primer.) The primer should be allowed to dry at least 30 minutes, but no longer than 24 hours, before the silicone rubber is applied. The primed surface must be protected at all times against contamination.

3. Preparation of Silicone Rubber: Two tenths of one percent by weight of curing agent, Thermolite 12, is added to the rubber compound and thoroughly blended. After mixing, the compound is deaerated in a vacuum (minimum of 28 inches of mercury) for no longer than 15 minutes. The mixed and deaerated sealant may be quick-frozen and stored for two weeks at -80 F.

4. Curing Cycle: The sealant is cured after 72 hours at ambient temperature if 20 percent or more of the surface is exposed to the air.

6.3.7.6 Manufacturing

a. Description: Multiple brush coats of RTV are applied to the aft side of the structural frame at Station 196, as shown in Figure 6.3.7.6-1. The thickness is as specified on the engineering drawing and application and cure are as specified in the applicable process specification.

b. Tooling and Equipment: Only templates and equipment such as brushes are required.

6.3.7.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control

1. General: Routine controls were invoked relative to cleaning of the painted surfaces prior to silicone application, environmental control, primer application, catalyst addition, and cure times.

2. Process Verification Coupons: Process verification test coupons were cast from each mix of silicone rubber. After the required cure cycle, the Shore "A" hardness was verified to be 55 ± 10.

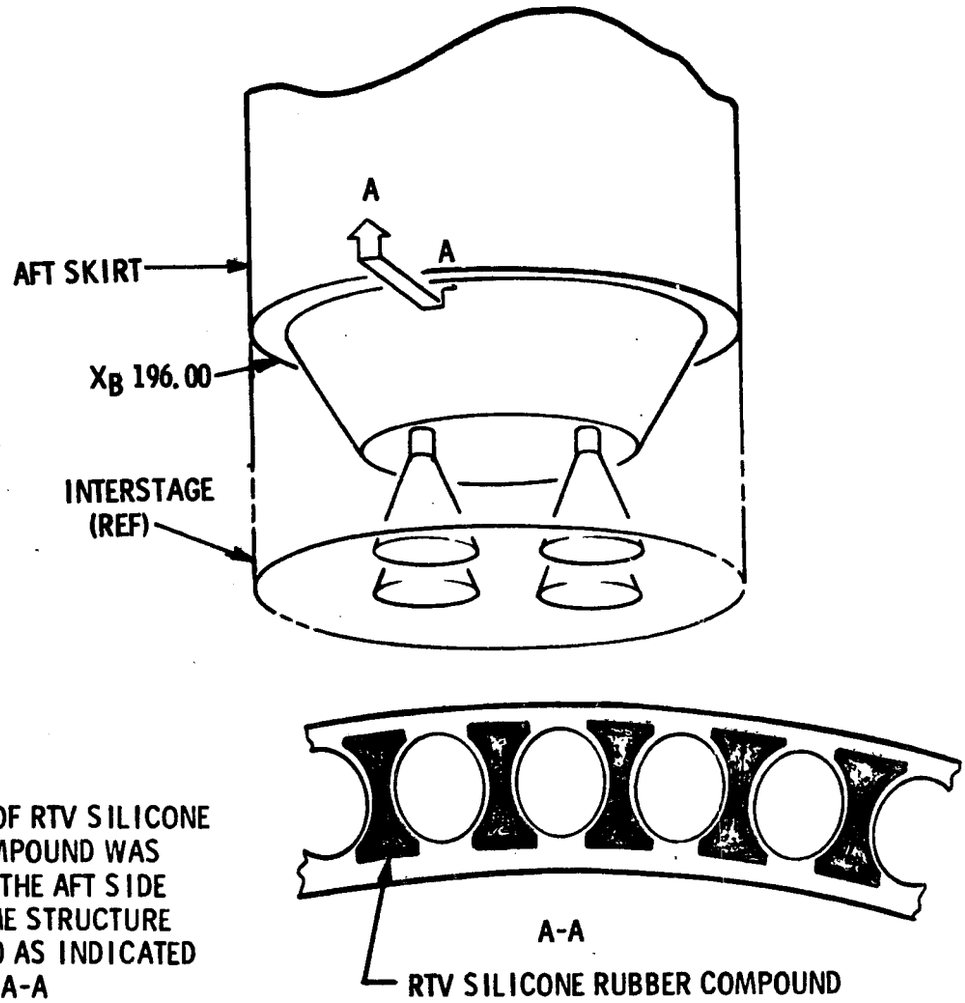


Figure 6.3.7.6-1. RTV Silicone Rubber Coating

6.3.7.8 Repair and Maintenance

No standard repair or maintenance procedures were developed.

6.3.7.9 Reliability

There was no failure mode effects analysis formulated at this component level because of the absence of any first-order failure modes. No reliability information is available.

6.3.7.10 Safety

a. Fabrication and Installation: Housekeeping and area cleanliness must receive particular emphasis to reduce the fire hazard and risk of contamination.

   Protective clothing must be worn while applying RTV. This clothing includes coveralls, gloves, and shoe covers.

Additional safety requirements are given in Paragraph 6.1.1.10.

b. RTV Insulation Use: Since RTV is a passive system, no special precautions—other than surface protection, regular inspection, and repair—are necessary during its use.

6.3.7.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. No data are available on required hours per square foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 6 weeks.

Subassembly - 0.

Installation - 2 weeks.

Checkout - 0.

c. Weight: The total as-installed weight is 1.40 lb/ft^2. Specific gravity (MB0130-034 Type III) = 1.35.

d. Thermal Performance: Q is not applicable to this insulation system because of varying heat rates; ρK is 10.1 $Btu/lb/hr-^oF-ft^4$.

6.3.8 Ablative Coating (Korotherm)

6.3.8.1 Description

This insulation system is used on the S-II for the thermal protection of the base heat-affected surfaces of the interstage internal structure during S-II boost (V7-531104). A coating of ablative material protects the substrate structure through sublimation and by the thermal resistance of the remaining layer of charred ablator.

The concept consists of spray-coating the structure with a silica-filled isocyanate resin material (Korotherm). The configuration is shown in Figures 6.3.8.1-1 and 6.3.8.1-2.

6.3.8.2 Application

a. Utilization: The Korotherm spray ablator coating system is used on the interior of the S-II interstage because of the complex protuberances. Korotherm also is used as an ablative thermal protection system on areas of the S-IVB having temperature conditions similar to those of the S-II.

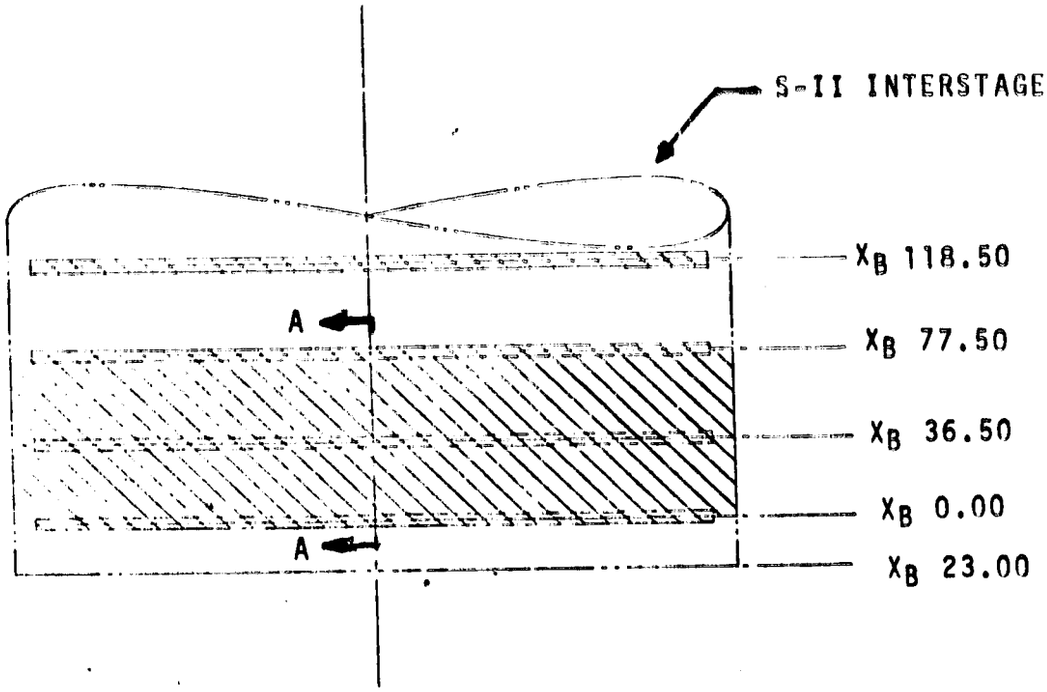
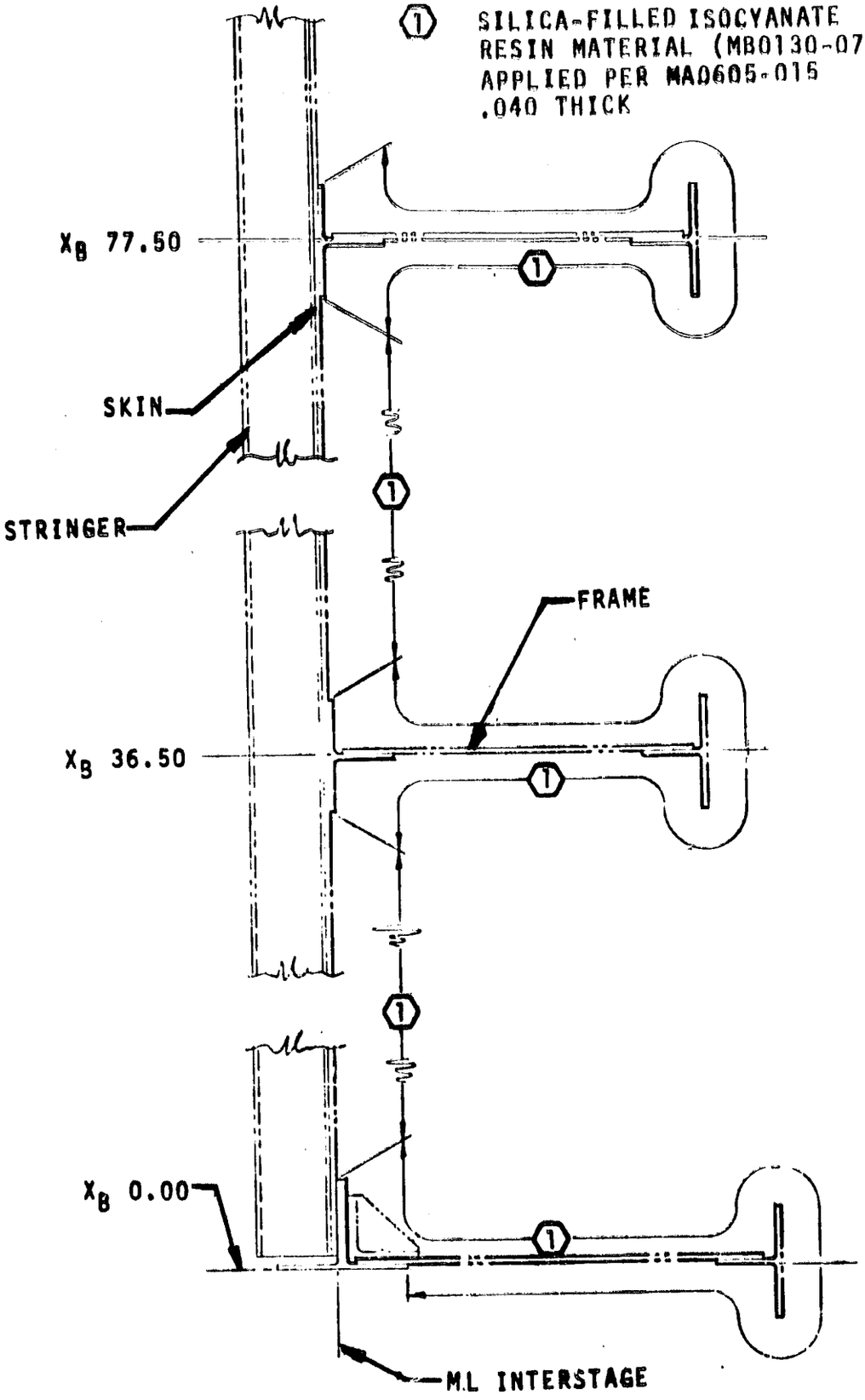


Figure 6.3.8.1-1. Ablative Coating

b. Performance Characteristics: This system has been used successfully on S-II-4 and subsequent vehicles. It has protected the structure within design limitations.

c. System Limitations: The system was developed to meet the requirements of the S-II program, as discussed in Section 5, and the materials and configuration are limited to the constraints of that program. The design functions as a thermal ablator to limit the temperature of the structure to a maximum of 500 F at the end of 30 seconds into S-II boost. The system is also limited to ground temperatures above -50 F.

d. Design Problems: The significant design problem was associated with cracking and debonding of the Korotherm due to low temperatures created by extended stage chill-down tests on S-II-9 and S-II-10. A test program was conducted to determine the cause of the failures. It was concluded that the material was sensitive to thickness, low temperature, and aging. The solution for S-II-9 was to remove and replace the defective material. For S-II-10, rework was not required because of the relaxed thermal and structural performance requirements established from results of previous flights. The S-II-10 rationale will be followed in the future.



SECTION A-A

Figure 6.3.8.1-2. Ablative Coating Detail

e. Verification Tests: Verification tests of the system consisted of the following:

1. A series of small-sample tests (Figure 6.3.8.2-1) were conducted in the plasma jet test facility to identify thermal properties of the system. Data from tests of material of various thicknesses are shown in Figures 6.3.8.2-2, 6.3.8.2-3, and 6.3.8.2-4.

2. Small-specimen tests were conducted to demonstrate the spray-on application characteristics. These characteristics were developed within manufacturing paint coating technology using conventional spray equipment.

3. Small samples were tested in the radiant heating facility to assess the ablative characteristics. A typical test profile is shown in Figure 6.3.8.2-5.

6.3.8.3 Thermal Performance

The aft skirt and interstage structures of the S-II are exposed to aerodynamic and solar heating during S-IC/S-II boost. The aerodynamic heating design environment and the effect of protuberances are described in SID 61-367. Solar heating was assumed equal to 438 Btu/hr-^{o}F-ft^{2}. The interstage structure is additionally exposed to base heating during the first 30 seconds of S-II boost. The base heating rates are those defined in the S-II Environmental Data Book (SID 61-473-1). Established structural temperature limits are 235 F during S-IC boost and 500 F for the interstage during the first 30 seconds of S-II boost (because the interstage is not loaded and is subsequently dropped).

To maintain the structural temperature limits on S-II-4 through S-II-15, the following thermal protection was provided: external cork insulation (MB0130-020 Type I) extended from Station -23 to Station 283 and internal skin and frame surfaces were protected by Korotherm (MB0130-074) insulation from Station 0 to Station 77.5. This concept is illustrated in Figure 7.3.3.6-1. The following material properties were assumed for the Korotherm insulation: density of 55 lb/ft^{3}, thermal conductivity of 0.12 Btu/hr-^{o}F-ft, and specific heat of 0.54 Btu/lb-^{o}F. It was further assumed that the initial temperature (at the beginning of S-IC boost) of the Korotherm-protected structure was 80 F.

These assumptions and material properties were used in a thermal analysis digital computer program to determine the transient temperature response of the aft skirt and interstage structure. Detailed results of this analysis are presented in Paragraph 7.3.6.1. Maximum temperatures of the structure on S-II-4 through S-II-15 were calculated to be 235 F or lower at the end of S-IC boost and 460 F or lower during the first 30 seconds of S-II boost, indicating that this insulation concept would provide the required thermal protection.

6.3.8.4 Structural Performance

Significant factors affecting the structural integrity of this insulation system are identical to those given for the RTV silicone rubber coating in Paragraph 6.3.7.4.

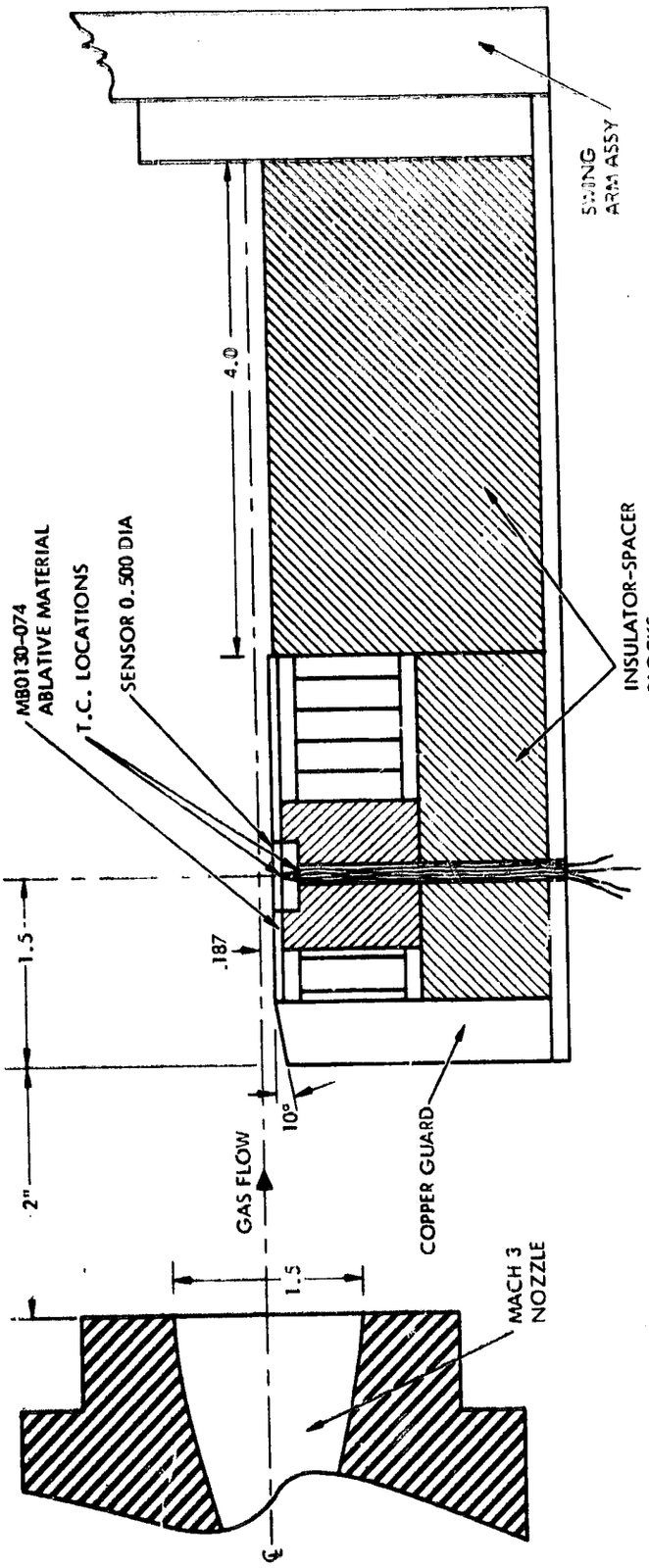


Figure 6.3.8.2-1. Cross-Section of Specimen Holder Positioned in Hyperthermal Tunnel Plasma Jet Facility

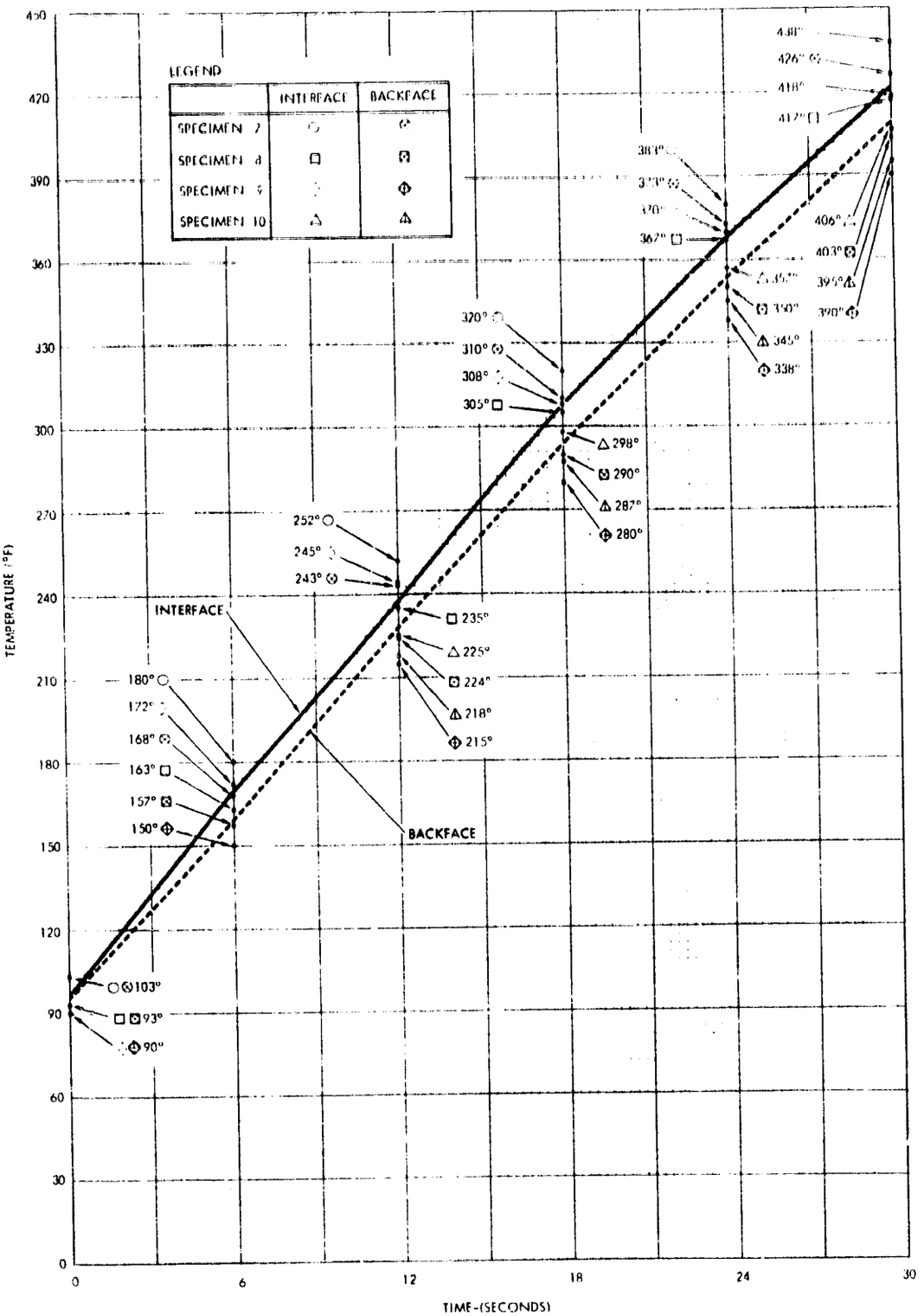


Figure 6.3.8.2-2. Time/Temperature History - 0.015-Inch Thick Ablative Specimens

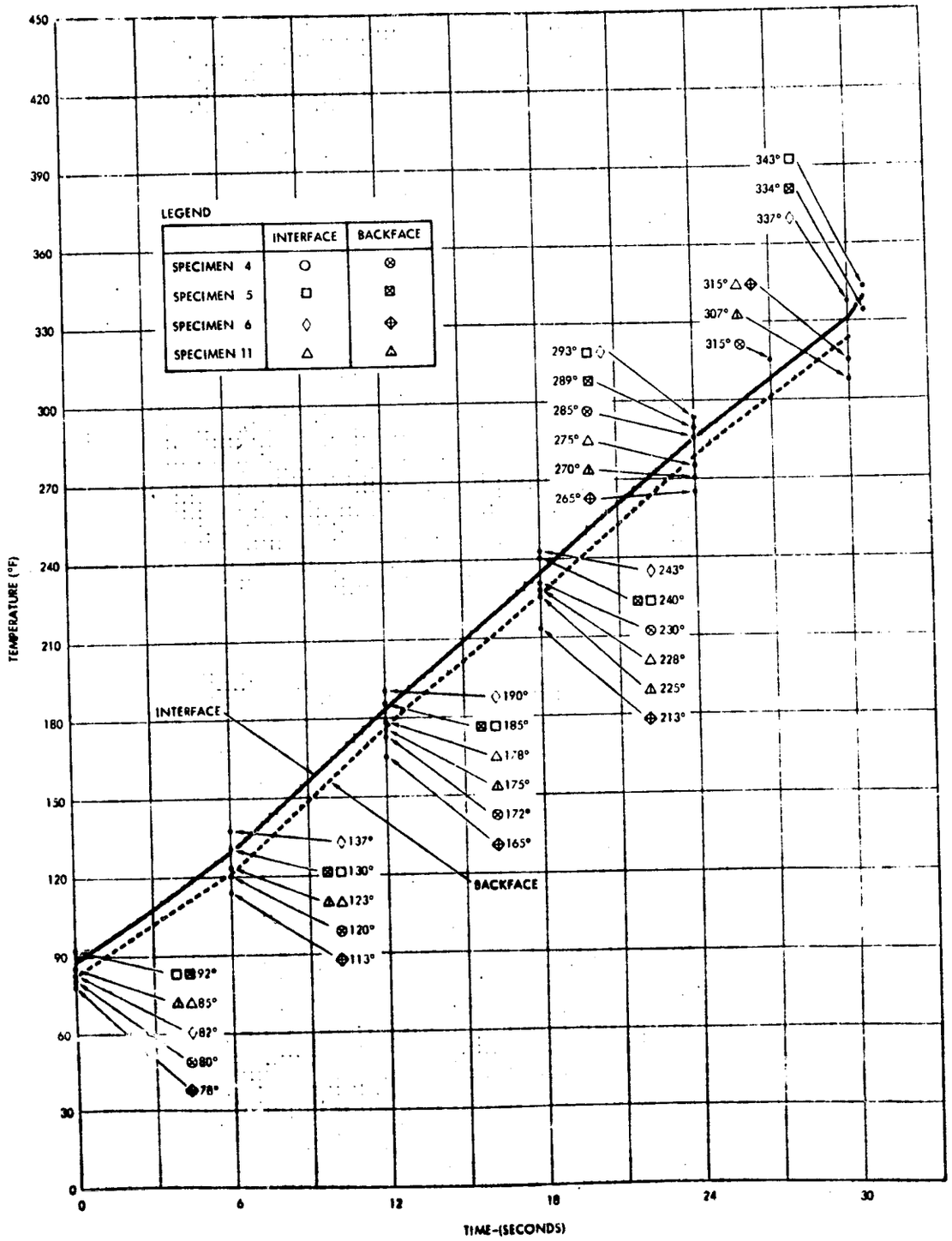


Figure 6.3.8.2-3. Time/Temperature History - 0.030-Inch Thick Ablative Specimens

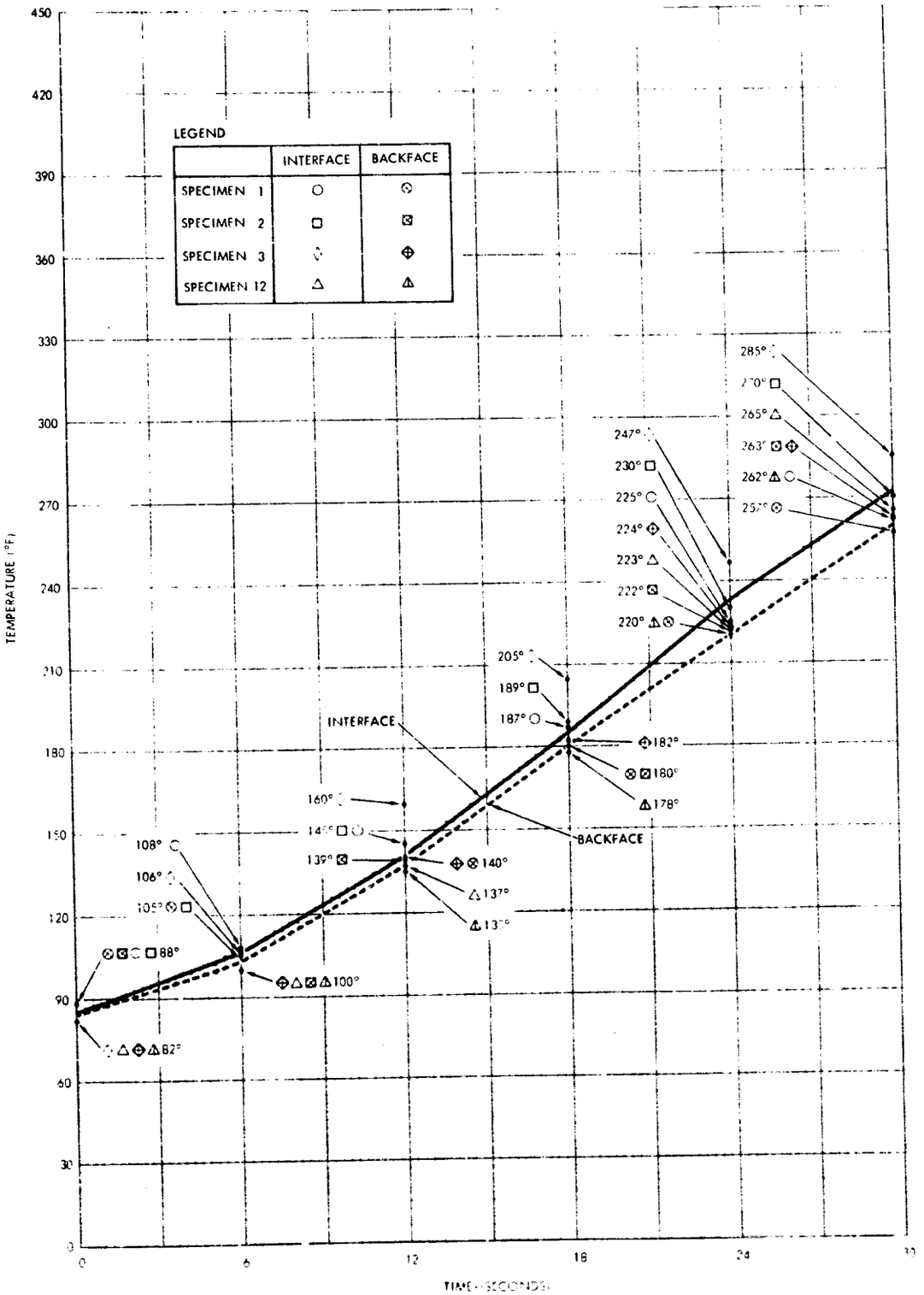


Figure 6.3.8.2-4. Time/Temperature History - 0.045-Inch Thick Ablative Specimens

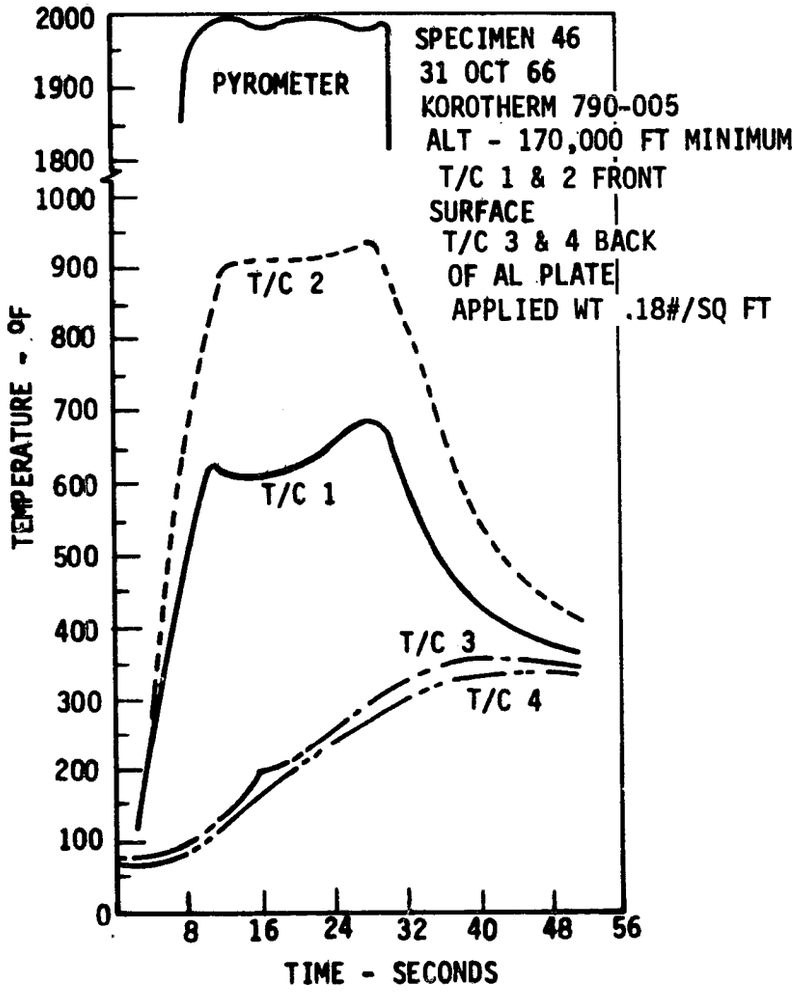


Figure 6.3.8.2-5. Base Heating Test, Time/Temperature Curve - Specimen Number 46

6.3.8.5 Materials and Processes

a. Material: The ablative insulation is silica-filled isocyanate resin.

b. Processes: The ablative coating is applied to the inner surface (Figure 6.3.8.1-1) of the interstage structure in accordance with MA0605-015.

1. Environment: The temperature of the area in which the ablative compound is applied is maintained at 60 to 90 F, with a relative humidity no more than 70 percent.

2. Surface Preparation: All primed surfaces are cleaned with solvent (MB0210-005) and wiped dry with cheesecloth. The maximum time interval between surface preparation and application of the ablative compound is 24 hours.

3. Preparation: Four parts by weight of Part A is mixed with one part by weight of Part B until homogeneous—the maximum batch not to exceed 5 pounds. When thinning is required, eight to ten parts by weight of reagent-grade acetone is added to 100 parts by weight of mixed ablative compound.

4. Application: The material is sprayed on with dry air having a maximum dew point of 20 F and containing no more than three ppm oil in an even cross-coat pattern.

5. Cure: Cure between coats is not required for thicknesses up to 0.030 inch. For thicknesses greater than 0.030 inch, 1/2 hour to 24 hours of air-dry is required between each 0.030-inch thickness. The ablator must be cured at least 168 hours before stress is applied or it is subjected to temperatures below 20 F or above 150 F. The cured ablator must have a minimum Shore A hardness of 80 and be free of blisters, sags, runs, streaks, and bare spots.

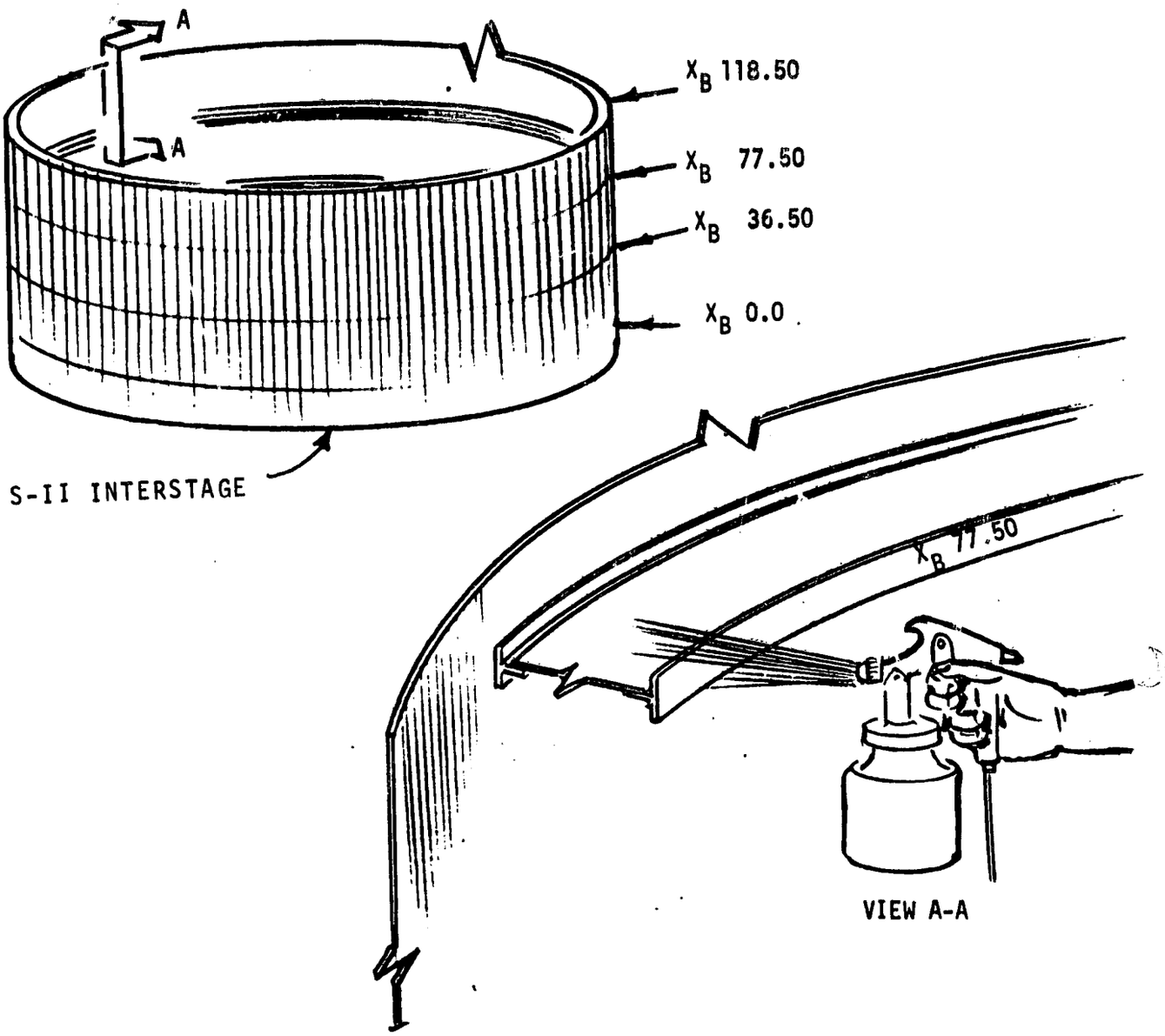
6.3.8.6 Manufacturing

a. Description: The interstage structure is cleaned thoroughly with a solvent. The internal circumferential surface is sprayed with two coats of ablative compound consisting of resin material filled with silica fibers and allowed to cure between coatings. Rough spots are sanded and cavities spatula-filled with ablative compound. See manufacturing breakdown (Figure 6.3.8.6-1) for illustration of ablator application.

b. Tooling and Equipment: No special tooling is required; standard paint spray equipment is used.

6.3.8.7 Quality Assurance

a. Raw Material Validation (MA0605-015): The ablative coating material was validated within 30 days of production use by testing for hardness and tape adhesion properties, as established in MB0130-074.



- INTERSTAGE WAS CLEANED
- TWO COATS ABLATIVE COMPOUND WERE APPLIED TO THE INTERIOR SURFACE AT X_B 000, X_B 36.50, X_B 77.50 AND X_B 118.50

Figure 6.3.8.6-1. Ablative Coating

b. Subassembly Process Control, MA0605-015 (Figures 6.3.8.1-1 and 6.3.8.1-2):

1. General: Routine controls were invoked relative to cleaning of the painted interstage, environmental control during spray and cure operations, and mixing of the ablative compound for spraying.

2. Process Verification Coupons: Process verification test coupons were fabricated simultaneously with application of the ablative compound to the interstage. The coupons were representative of the same surface preparation, storage, handling, open assembly time, and cure cycle of the production assembly. Following complete cure, the adhesion of the compound was verified by tape test defined in MB0130-074. In addition, ablative compound castings were prepared for verification of proper Shore "A" hardness.

c. Quality Verification of the Final Assembly:

1. Visual Inspection: The insulated areas of the interstage were visually inspected to verify the structure to be free of blisters, sags, runs, streaks, or bare spots.

2. Thickness: Coating thickness was verified to be within drawing tolerance by the use of a Fischer Permascope.

6.3.8.8 Repair and Maintenance

a. Repair: In-process rework of scratched or gouged ablative compound is allowed. The damaged area is cleaned with MEK and filled with ablative compound 0.02 inch above the surrounding compound. All other repairs require full Material Review Board approval.

b. Maintenance: No special maintenance is required.

6.3.8.9 Reliability

There was no failure mode effects analysis formulated at this component level because of the absence of any obvious first-order failure modes. No reliability information is available.

6.3.8.10 Safety

a. Fabrication and Installation: Ventilation must be provided during spraying operations to reduce the isocyanate outgassed below a concentration of 0.02 ppm.

All electrical equipment must comply with California Electrical Safety Orders or National Electric Code for Class II, Division I, environments.

Housekeeping and area cleanliness must be emphasized to reduce fire hazards and risk of contamination.

Protective clothing must be worn by personnel spraying Korotherm. This clothing includes airline masks, coverall, gloves, and shoe covers.

Additional safety requirements are given in Paragraph 6.1.1.10.

b. Ablative Coating Use: Korotherm is a passive system. Consequently, no special precautions—other than surface protection, regular inspection, and repair—are required during its use.

6.3.8.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are an indication of the installation complexity of the insulation system and are derived from Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and indicate the insulation system's relative cost. No data are available on the hours required per square foot.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 10 weeks.

Subassembly - 0.

Installation - 3 weeks.

Checkout - 0.

c. Weight: The total as-installed weight is 1.81 lb/ft^2. Korotherm (MB0130-074) specific gravity - 0.88.

d. Thermal Performance: Q is not applicable to this insulation because of varying S-II heat rates; ρK is 6.58 $Btu/lb/hr-{}^oF-ft^4$.

6.4 OTHER INSULATION SYSTEM APPLICATIONS

Two special-purpose insulation systems are discussed in this section. They are (1) a system of cork and MLI-fiberglass used to protect avionic equipment containers and (2) a nylon fabric-plastic film membrane seal used to isolate an inaccessible joint which is uninsulated.

6.4.1 Thermal Protection for Avionic Equipment

6.4.1.1 Description

A cork thermal control system was used on S-II to maintain the ambient temperature inside the avionic equipment containers within specified limits. The system consists of a passive insulation and an active gaseous purge. The passive insulation serves a dual purpose. In conjunction with the warm gaseous purge, it provides low-temperature thermal protection during tanked

ground-hold conditions and high-temperature protection from base heating during S-II boost. The purge system also provides cooling capability during warm ground checkout operations.

The passive insulation consists of adding sheet cork on the outside of the container base and on the inside of the container sides and cover. The concept (V7-540803) is shown in Figures 6.4.1.1-1 and 6.4.1.1-2.

An MLI-fiberglass thermal control system was proposed for the avionic equipment containers on the INT-21 launch vehicle. In addition to providing thermal protection during tanked ground hold and boost, this system provides thermal protection during short-term orbital operations.

The system consists of a fibrous glass material containing a silicone resin binder with a fiberglass cover on the outside of the container base and MLI on the sides and cover inside. This concept is shown in Figures 6.4.1.1-1 and 6.4.1.1-3. Heaters are provided inside the containers for active thermal control during orbital operations. Fiberglass spacers, CRES mounting brackets, and special surface coatings also are utilized to maximize the efficiency of the passive thermal control system (SD 70-687).

6.4.1.2 Application

a. Utilization: The electronic components and other equipment required for vehicle operations and communications are generally grouped by system and enclosed in containers. Depending on the requirements of the electronic components (see Section 5.0), the containers are insulated to provide thermal protection from the environment, from adjacent radiative/absorptive surfaces, and from space. Purge gas is directed through the containers for dynamic cooling or heating.

   The cork system shown in Figures 6.4.1.1-1 and 6.4.1.1-2 was used on the S-II stage. The MLI and fibrous glass system shown in Figure 6.4.1.1-3 was proposed for the INT-21 launch vehicle.

   The difference between these two systems is reflected by the passive insulation system, the first requiring protection for a short period on the ground and in launch, and the second for extended periods in space. These systems can be used for any similar application, depending on the availability of the purge gas.

b. Performance Characteristics: Performance of typical cork systems on the first two S-II launch stages are shown in Table 6.4.1.2-1. Characteristics for the MLI system proposed for INT-21 have not been developed.

c. System Limitations: The cork system was designed specifically for S-II stage requirements including environments, energy release, and time of operation. Limitations beyond these requirements must be based on the material properties and availability of purge gas.

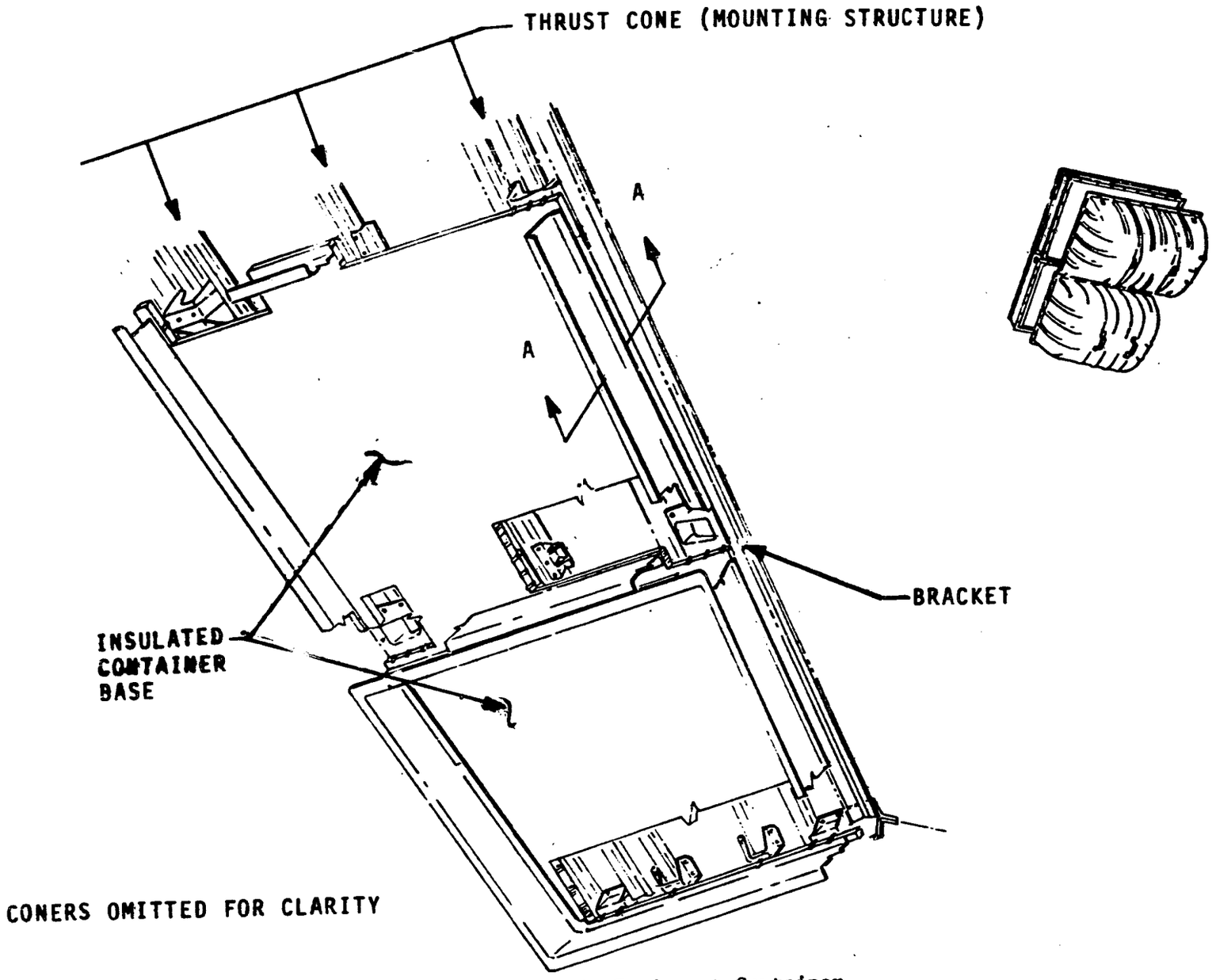


Figure 6.4.1.1-1. Avionic Equipment Container

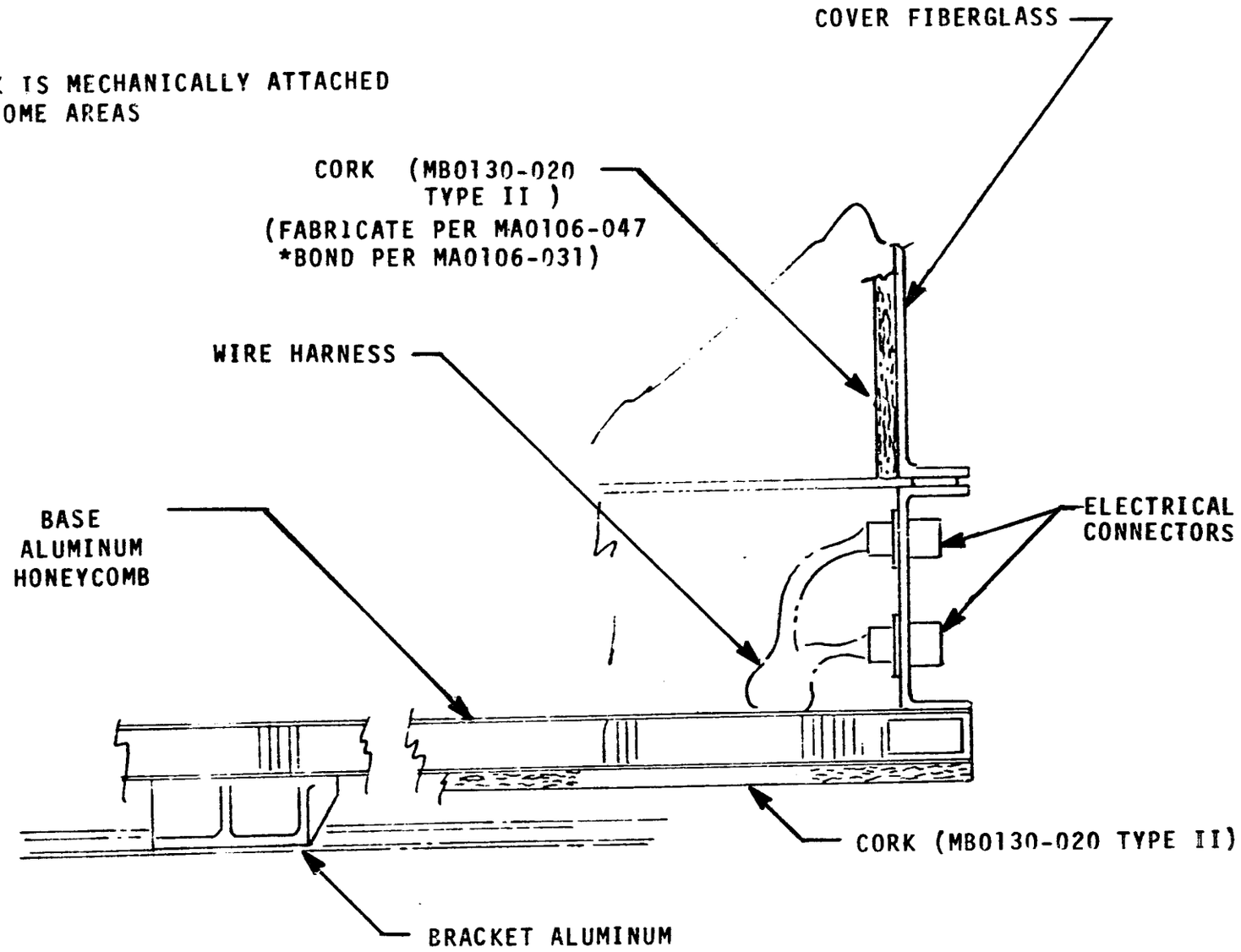


Figure 6.4.1.1-2. Container Detail

Space Division
North American Rockwell

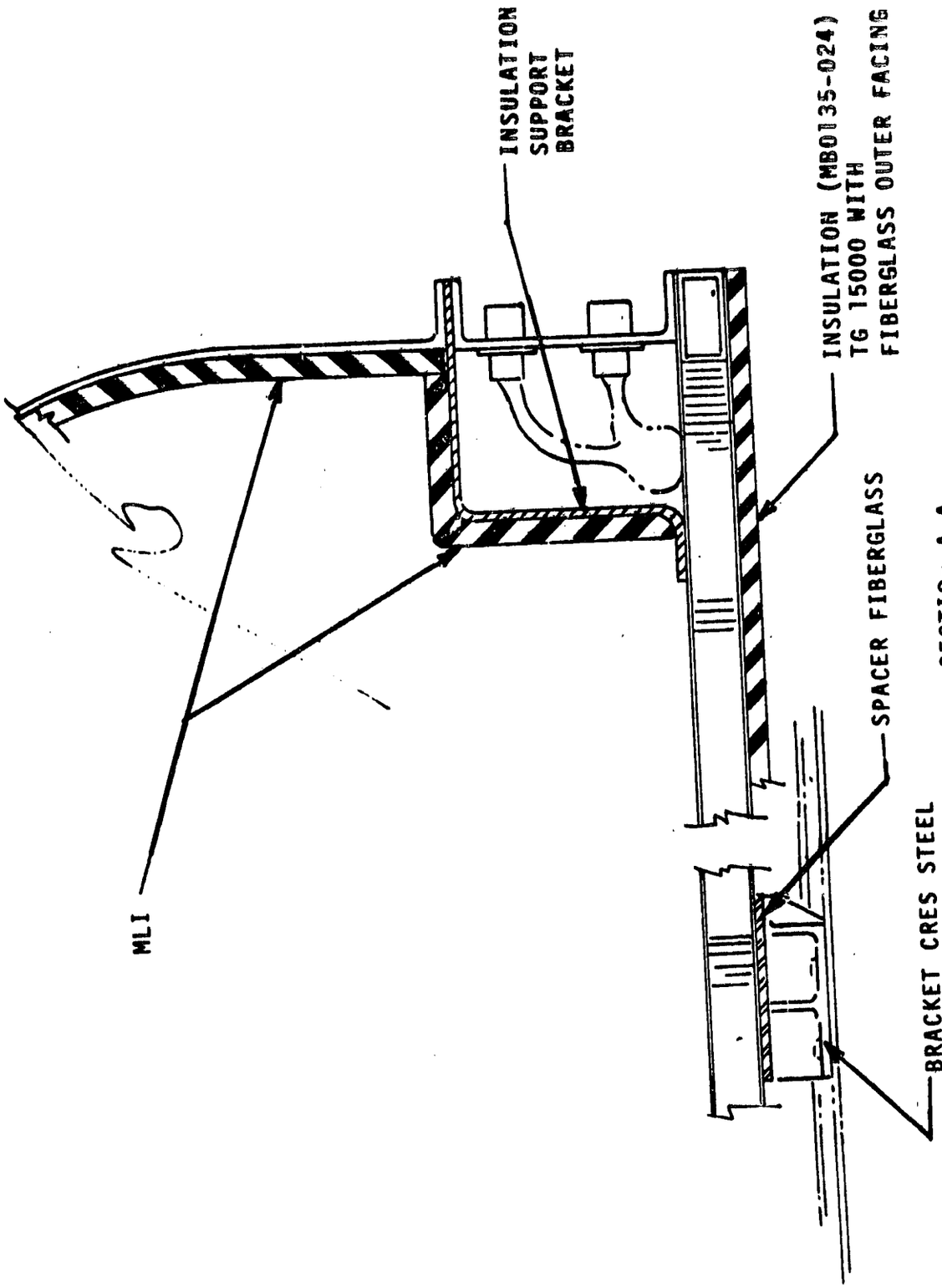


Figure 6.4.1.1-3. Container Detail

Table 6.4.1.2-1. Cork System Performance Characteristics

Element	Design Limit (°F)		AS 501		AS-502	
	Max.	Min.	Engine Chill (°F)	End Boost (°F)	Engine Chill (°F)	End Boost (°F)
GN_2 Flow - Forward	40	34	42.0	-	37.5	-
GN_2 Flow - Aft	37	31	32.5	-	34.0	-
GN_2 Temp. Forward	115	105	-	-	102.0	-
GN_2 Temp. Aft	115	105	114.0	-	111.0	-
Forward Container 220	140	0	63.0	60	60.0	63
Forward Container 223	140	-20	60.0	55	47.0	44
Aft Container 208	140	0	82.0	70	90.0	76
Aft Container 211	140	65	61.0	37	51.0	25

Similar limitations exist for an MLI system. In space the system must be rotated toward the sun and away from space to insure temperature control or adequate heating must be provided.

d. Design Problems: No major design problems were encountered with the container insulation system on the S-II stage. Development problems were associated with selection of orifices to balance the purge flow among the various containers.

e. Verification Tests: The system has been used on all S-II launches to date. Performance has been satisfactory.

6.4.1.3 Thermal Performance

a. Cork: S-II stage avionics equipment is located in containers within the engine compartment which are subjected to base heating throughout S-II boost. These containers utilize bonded cork insulation on the inner surface of the containers in order to limit the maximum internal wall temperature. In addition, a maximum mounting base temperature of 125 F is required for all containers. Bonded cork located within a fiberglass mounting base was employed where necessary to satisfy this requirement.

These containers are described in detail, including the density and thickness of the cork employed on each container in Paragraph 7.3.4.1. The detailed results of a thermal analysis of the adequacy of this insulation system are also presented.

The base heating rates, convective and radiant, vary with time during S-II boost as a function of: (1) the presence of the aft interstage structure during the first 30 seconds of S-II boost, and (2) the J-2 engine mixture ratio which is reduced after 350 seconds of S-II boost. The heating rates assumed in the thermal analysis are listed in Table 7.3.4.1-1.

The thermal properties of the 30-lb/ft^3 cork (MB0130-020, Type 1) assumed were: thermal conductivity equals 0.04 Btu/ft-hr-^{o}F and specific heat equals 0.40 Btu/lb-^{o}F. The thermal properties of the 8-lb/ft^3 cork (MB0130-020, Type II) assumed were: thermal conductivity equals 0.020 Btu/ft-hr-^{o}F at 0 F, 0.023 Btu/ft-hr-^{o}F at 140 F, and 0.029 Btu/ft-hr-^{o}F at 287 F, and 0.60 Btu/lb-^{o}F at 275 F.

These parameters served as input to a thermal analysis digital computer program (Thermal Analyzer Program): For the worst-case base heating environment, a one-engine-out boost, the interior surface temperature of the cork within all except three containers was found to reach 240 F. This was 40 F higher than the design requirement used in previous studies. A further analysis was therefore conducted to determine the effect on the avionics components within these containers of allowing the internal container wall temperature to increase to 240 F. The study, which assumed that the avionics components are heated by radiation from the interior surfaces of the container, indicated that a maximum internal wall temperature of 240 F will not overheat the components. The largest temperature increase for any component was 18 F at the end of a one-engine-out boost, assuming an initial component temperature of 60 F. Therefore, the container cork thickness specified in Paragraph 7.3.4.1 is adequate.

Of the remaining three containers, two have lower interior surface temperatures than 240 F and are therefore no problem. The cover of Container 207A2, however, reaches a maximum interior wall temperature of 390 F. The radiant heat transfer to a typical component within this container was calculated, assuming an interior cover temperature of 390 F. The calculated rate was found to be 0.054 Btu/ft^2 which is low enough to preclude damage to components. The study further showed that the maximum mounting base temperature will be satisfied for all containers by the prescribed insulation design.

b. MLI and Fibrous Glass/Silicone Resin Binder: To perform an INT-21 mission, the S-II stage avionics components within the forward and aft equipment containers must be capable of: (1) withstanding the prelaunch solar heating and the aerodynamic and base heating environments existing throughout S-IC/S-II boost, and (2) operating for 24 hours in an orbital thermal environment. The temperature of most of the avionics equipment in question must be maintained within the range of 0 to 140 F. However, there are a few control modules that have been qualified to operate in only a 0 to 125 F environment.

It was determined based on thermal analyses (SD 70-687), that the avionics components could be maintained within the above temperature limits by: (1) modifying the existing S-II equipment containers, and (2) the addition of electric heaters to some aft equipment containers.

Container modifications include replacing the current S-II aft equipment container fiberglass covers with aluminum covers and applying Z-93 white inorganic thermal control coating to the external surface of the aluminum covers. The Z-93 coating is required to obtain a relatively low ratio of solar absorptivity (α) to infrared emissivity (ϵ) of approximately 0.16 while exposed to direct solar heating. Surface coatings required on other external surfaces of the aft containers and on internal surfaces are varied depending on solar heating and equipment heat dissipation. The internal insulation on the cover and fiberglass walls is a combination of Kapton and NRC-2. A layer of Kapton is required between the external wall and NRC-2 because of its performance at elevated temperatures of approximately 270 F caused by base heating experienced during S-II boost. NRC-2 is used for the remainder of the insulation blanket because of its lower cost. TG15000, a fibrous glass/silicone resin binder, is used externally underneath the aluminum honeycomb mounting base because it is more compatible with the present container design. Insulation thickness varied between 1/8 and 1/2 inch depending on environmental conditions and equipment heating.

The basic construction of the fiberglass forward containers was not altered except for surface coating and insulation. Containers with high internal heat dissipations require Thermatrol white paint, with a high emissivity of approximately 0.95, on external and internal surfaces to dissipate the internal heat, while containers with low heat dissipations require aluminum foil and aluminum silicone paint on external and internal surfaces, respectively, to minimize radiation heat transfer. Aluminum foil and aluminum silicone paint have relatively low emissivities of approximately 0.10 and 0.28, respectively. NRC-2 insulation is used internally on the covers and walls of Containers 221, D and E, and TG15000 is used underneath the base of all containers except Container 223. Insulation thickness for the forward containers also varies between 1/8 and 1/2 inch. Container 223 requires no thermal control modification since it is only required through S-II boost.

The aerodynamic, solar, and base heating environments to which the avionics equipment containers are exposed during the prelaunch period and throughout S-IC and S-II boost was assumed to be the same environment experienced during an LOR mission.

The orbital thermal environments used in this study were generated utilizing the Space Vehicle Thermal Environment Program described in SD 69-507. Based on this program, the incident orbital heat loads to each equipment container was determined. To minimize the effect of solar heat input, a surface coating (Z-93) with a low solar absorptivity (α) to infrared emissivity (ϵ) ratio is recommended for application on the external surface of the thrust cone and the covers of the aft containers. The solar absorptivity of Z-93 increases from 0.14 to 0.25 after 500 hours exposure to 500 F but maintains a relatively low α/ϵ ratio of 0.27. Z-93 was selected in preference to other coatings because of its resistance to degradation due to base heating effects.

The equipment containers located in the forward skirt area are not exposed to base heating or direct solar radiation. Therefore, any high infrared emittance coating is adequate for the surfaces of the containers containing high heat-producing equipment. The use of internal and external coatings which provide high infrared emittance allows the container to dissipate this high internal heat by radiation to the cool surface of the LH_2 forward dome and aft thrust cone. The thermal properties of the coatings and insulations employed are contained in SD 70-687, and in Tables 7.3.4.1-5 and 7.3.4.1-7 of Paragraph 7.3.4.1. The study assumed that the orbital system employs a vehicle attitude control system so as not to expose containers with high equipment heat dissipations to high solar heating. For containers housing low heat-producing equipment and which are not exposed to direct solar radiation, it is recommended that the container internal surfaces be coated with high reflective coating and the exterior surface coated with a low emittance coating, thus minimizing the need for internal electric heaters. The recommended coatings for the interior and exterior surfaces of the forward and aft equipment containers are given in Table 7.3.4.1-6.

By locating high heat-dissipating equipment in containers which are exposed to the least incident radiation (cold sides) and by the extensive use of passive thermal control techniques (i.e., special coatings, use of honeycomb mounting, etc), the need for active thermal control devices was minimized. This effort consisted of individual application of passive control devices to each container based on its internal heat dissipation, incident orbital heating, and the prelaunch and launch environments. This approach made it possible to eliminate the need for an active cooling system and to minimize the need for electrical heaters. The incident orbital heating to the containers varies depending on the orbital flight attitude chosen (Y axis perpendicular to the orbit plane with nose forward in the direction of flight, or a solar orientation with vehicle -Z axis to the sun) and on the angle maintained between the orbit plane and the sun (β angle). Both flight attitudes and β angles from 0 to 80 degrees were investigated. The results are summarized in Table 7.3.4.1-4. Based on these studies, none of the forward containers require electrical heaters. Aft Containers 206A31 B and C will require electrical heaters when orbiting in the design (Y-POP) flight mode. For a -Z axis to the sun flight mode, aft Containers 207 and B would require heaters. All heaters are designed with thermal switches which activate them at 8 F and turn them off at 10 F.

6.4.1.4 Structural Performance

Significant factors affecting the structural integrity of this insulation system are identical to those given for the cork insulation in Paragraph 6.1.8.4 and for the MLI given in Paragraph 6.1.10.4.

6.4.1.5 Materials and Processes

This discussion is limited to the application of cork insulation since no processing was developed for the use of multi-layer insulation.

a. Materials:

1. Cork (MB0130-020 Type II).

2. Silicone rubber, room-temperature vulcanizing (MB0130-019).

3. Primer for silicone rubber (MB0125-038).

b. Process: The cork insulation details are fabricated in accordance with MA0106-047 and bonded in accordance with MA0106-031.

1. Material Storage and Handling: All materials are stored and handled in accordance with the applicable specifications.

2. Surface Preparation: Faying surfaces on the interior of the fiberglass containers are abraded and solvent-wiped.

3. Preparation of Flexible Epoxy-Polyamide Adhesive: The adhesive is prepared as a two-component system. Just prior to bonding Parts A and B are mixed thoroughly in a 50-50 weight ratio. The working life of a 100-gram mass of the activated adhesive is 1-1/2 to 2 hours at 77 ± 5 F.

4. Where sheets of cork composition of a specific thickness are required in dimensions larger than standard available sheet size, two or more sheets may be bonded together using a butt, scarf, or half-lap joint configuration and the above flexible epoxy-polyamide adhesive system.

5. Preforming: The cork composition is preformed to match the faying surface in one of the following techniques.

(a) Simple Shapes: Preformed without fracturing the cork.

(1) The cork composition detail is placed in the tool and positive or vacuum bag pressure sufficient to establish and maintain the required contour is applied. The assembly is heated to 235 ± 10 F and maintained for 20 ± 5 minutes.

(2) The assembly is cooled to room temperature under pressure before removing the cork detail.

(b) Complex Shapes: If the shape is sufficiently complex the cork may fracture when bent at room temperature.

(1) The cork composition detail is placed in a preheated oven for 15 ± 5 minutes at 235 ± 10 F.

(2) The detail is removed and immediately placed on a preheated (235 ± 10 F) restraining fixture. Sufficient pressure is applied to establish and maintain the required contour.

(3) The detail is cooled to room temperature before it is removed from the fixture.

6. Application of Cork Sheet: A uniform film of adhesive (MB0130-042), 10-15 mils thick, is applied to each surface to be bonded, using brush or spatula. Contact pressure of 1 psi minimum is maintained between the mating parts for a minimum of 24 hours. The assembly is cured with one of the procedures given in MA0106-038.

7. Moisture- and Fungus-Resistant Coating: All exposed surfaces of cork are treated with a moisture-resistant coating in accordance with specification.

6.4.1.6 Manufacturing

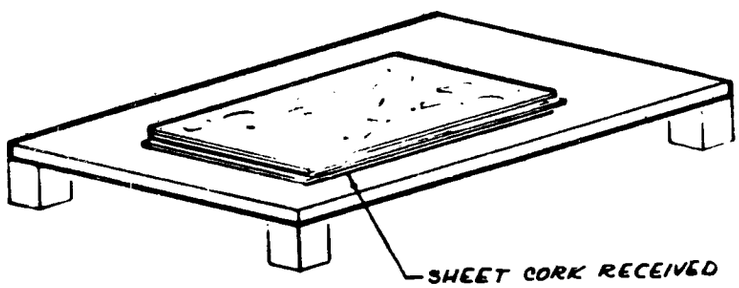
a. Description: Cork lining for the inside and adjacent structure of equipment containers was cut from sheet cork. Layouts of parts to be cut were placed on the cork on a work table. Knife cuts were made using a straightedge for straight-line cuts and templates where irregular cuts were required. Cork was bonded or mechanically attached. For mechanical attachment, the cork was drilled from layouts. Fasteners were installed and tightened to hold the cork in place, as was the case in the basic structure under the honeycomb base. Cork surfaces to be bonded to structure were coated with adhesive using a spatula. Pressure was applied through the vacuum system during the cure cycle. After the adhesive was heat-cured, the rough spots and irregularities were sanded smooth. Any pinholes or small cavities were filled with a sealer rubbed in with a hand squeegee. When curing of the sealant was completed, the cork was sprayed with two coats of fungus-resistant chemical with sufficient drying time between coatings.

The manufacturing flow and sequences are shown in Figure 6.4.1.6-1.

b. Tooling and Equipment: Tooling and equipment was similar to that described in Paragraph 6.1.8.6.

6.4.1.7 Quality Assurance

Two thermal protection insulation systems for avionic equipment are described in Paragraph 6.4.1.1. The basic insulation system consists of sheet cork bonded to the structure. The secondary system employs MLI insulation in conjunction with the sheet cork. MLI with sheet cork did not reach production status on the Saturn S-II program; hence, no formal quality assurance procedures were established for this system. This section is therefore limited to the quality assurance provisions for the application of sheet cork as shown in Figures 6.4.1.1-1 and 6.4.1.1-2.



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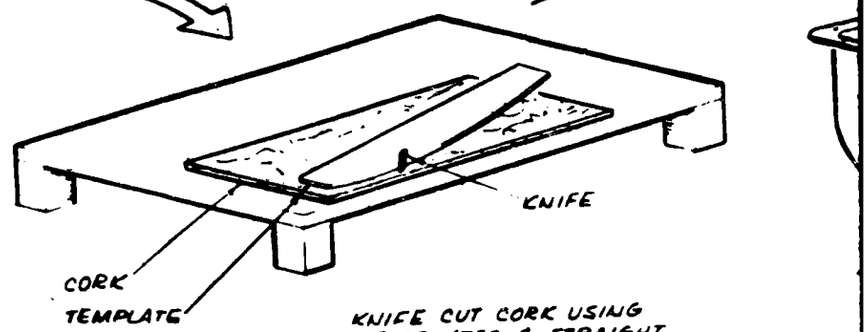
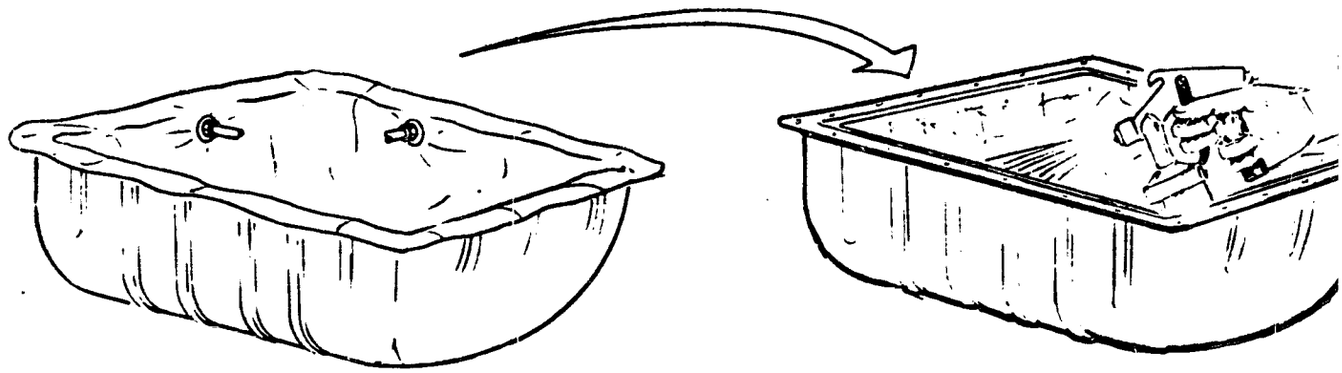


KNIFE CUT CORK USING TEMPLATES & STRAIGHT EDGE

2



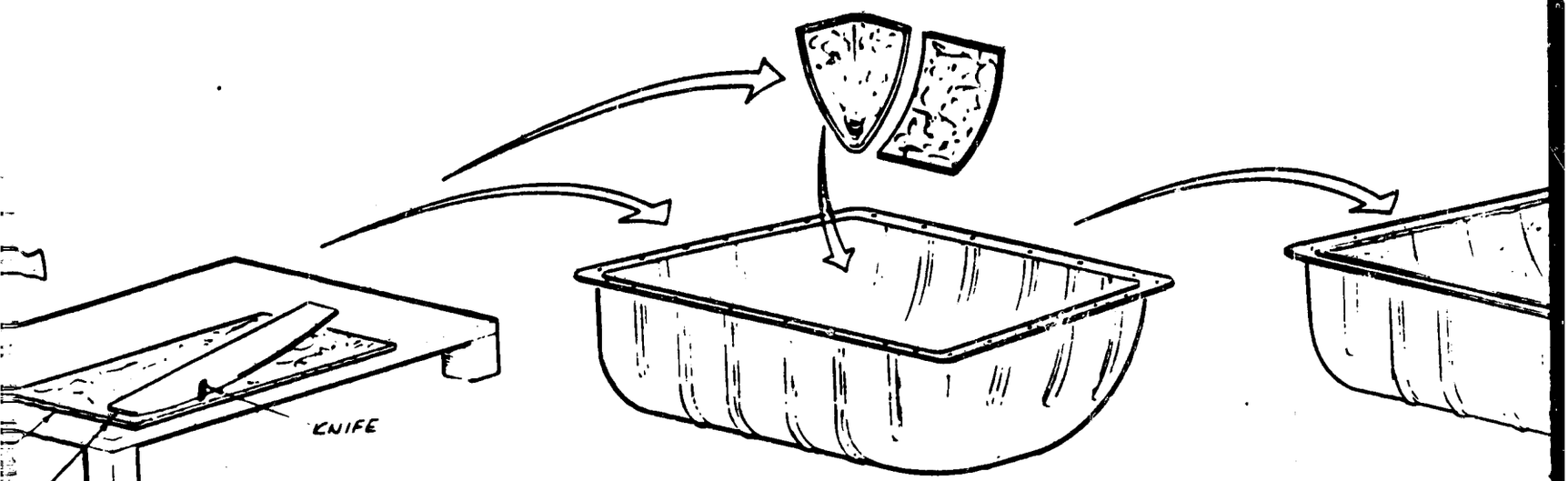
• PRESSURE WAS APPLIED TO THE CORK USING THE VACUUM SYSTEM DURING THE CURE CYCLE

5

• SPRAY WITH TWO COATS OF FUNG RESISTANT CHEMICAL WITH SUFF DRYING TIME BETWEEN COATS

6

FOLDOUT FRAME



KNIFE CUT CORK USING TEMPLATES & STRAIGHT EDGE

2

3

- PREFIT CORK
- REMOVE & CLEAN

4

- BOND CORK
- USE VACUUM
- ROUGH CUTS SMOOTH CONS
- SMALL CAVITI

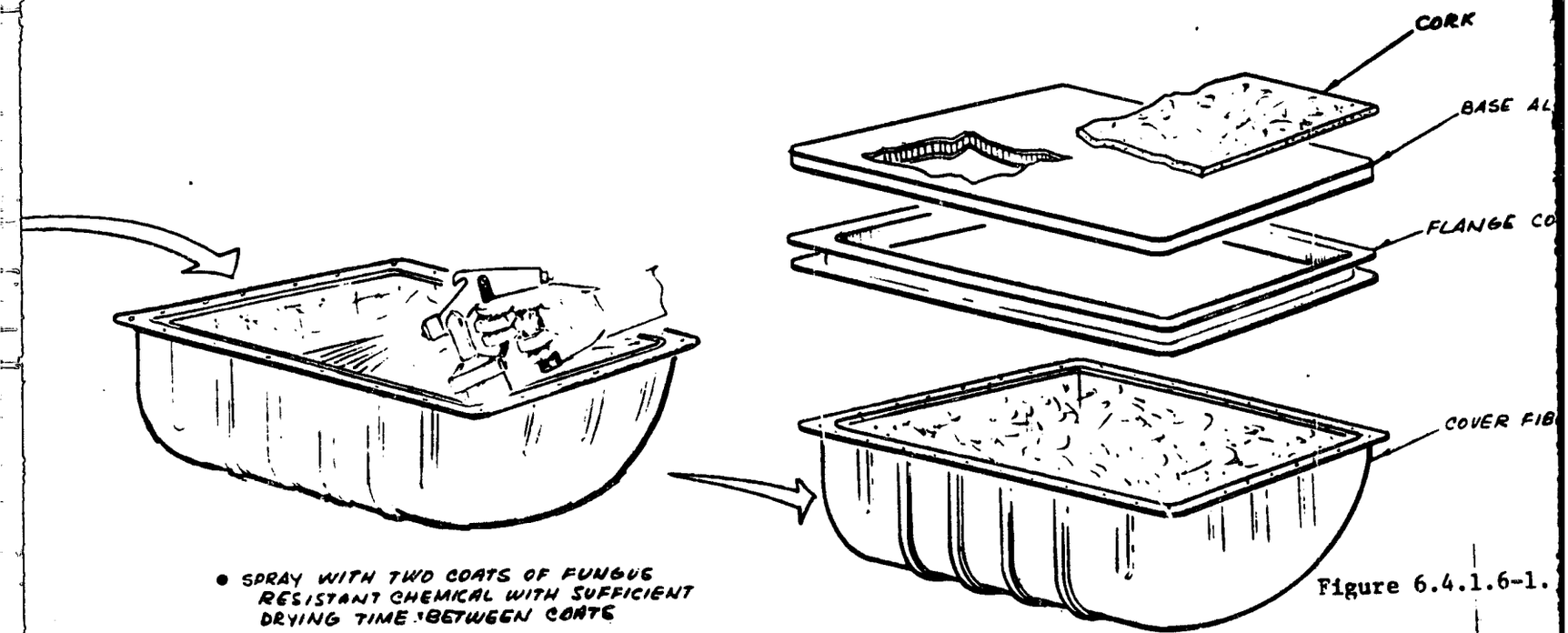


Figure 6.4.1.6-1.

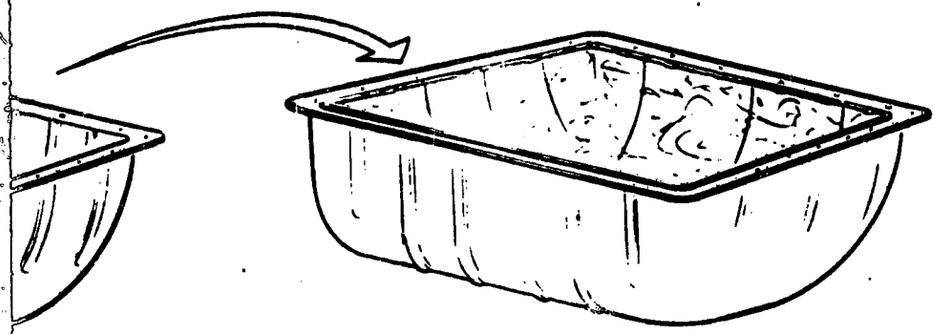
- SPRAY WITH TWO COATS OF FUNGUS RESISTANT CHEMICAL WITH SUFFICIENT DRYING TIME BETWEEN COATS

6

- SHEET CORK WAS ADDED TO THE OUTSIDE OF THE CONTAINER BASE. AFTER BONDING AND CURE, CORK WAS SPRAYED WITH TWO COATS OF FUNGUS RESISTANT CHEMICAL

7

FOLDOUT FRAME 2



4

- BOND CORK TO INSIDE OF BOX
- USE VACUUM SYSTEM DURING CURE CYCLE
- ROUGH SPOTS & IRREGULARITIES SANDED TO A SMOOTH CONSISTENCY
- SMALL CAVITIES FILLED WITH A SEALER

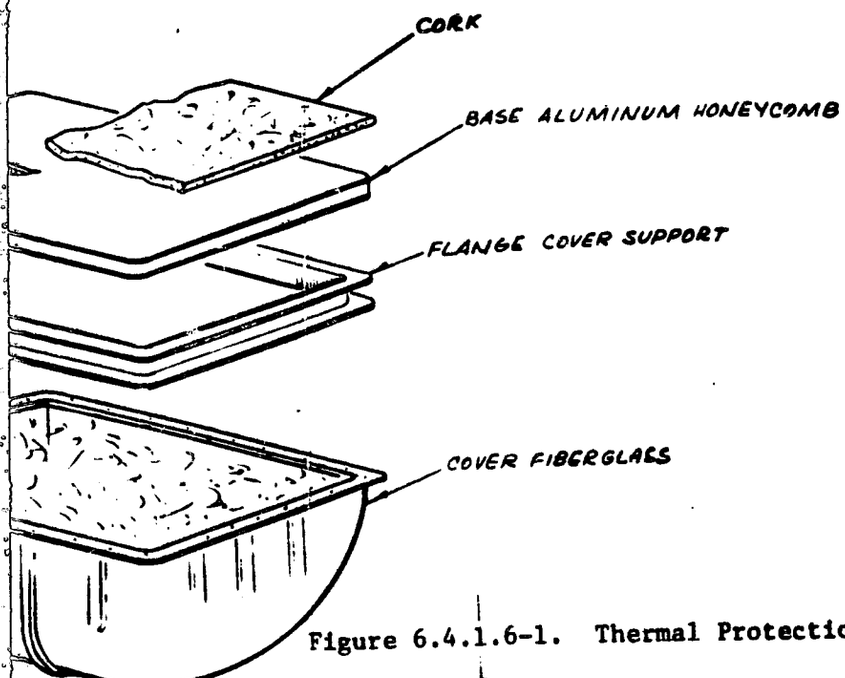


Figure 6.4.1.6-1. Thermal Protection for Avionic Equipment

7

S ADDED TO THE OUTSIDE
ER BASE. AFTER BONDING AND
S SPRAYED WITH TWO COATS OF
TANT CHEMICAL

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control:

1. General: Routine controls were invoked relative to surface preparation, primer application, catalyst addition, and cure times.

2. Process Verification Coupons: Metal-to-metal lap shear strength test coupons were fabricated simultaneously with the production bonding operations. A minimum lap shear strength of 50 psi was required.

c. Quality Verification of Final Assembly: Final acceptance was based on a visual inspection for proper cure, fit, and overall conformance to drawing requirements.

6.4.1.8 Repair and Maintenance

a. Repair: No standard repair procedures were developed.

b. Maintenance: All cork composition surfaces not subsequently protected with a fungus-resistant coating are treated with fungicide in accordance with MA0106-047.

6.4.1.9 Reliability

There was no failure mode effects analysis formulated at this component level because of the absence of any obvious first-order failure modes. No reliability information is available.

6.4.1.10 Safety

a. Cork: The safety considerations of cork insulation are given in Paragraph 6.3.6.10.

b. MLI and Fibrous Glass/Silicone Resin Binder: This insulation system is conceptual only. Hazard analysis has not been conducted and insufficient operational experience has been accumulated to formulate safety requirements.

6.4.1.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and are an indicator of its relative cost. No data are available on the cost of this system.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 10 weeks (cork), 14 weeks (NRC-2).

Subassembly - 0.

Installation - 1 week.

Checkout - 0.

c. Weight: The total as-installed weights are:

1. Cork System:

(a) Cork, 0.25-inch thick (MB0130-120 Type 2) - 0.522 lb/ft^3

(b) Adhesive (MB0120-008) - 0.031 lb/ft^2

Total 0.553 lb/ft^2

2. Fiberglass batting (TG15,000) - 0.062 lb/ft^2

3. Multi-layer insulation (NRC-2) - 0.115 lb/ft^2

6.4.2 Membrane Seal

6.4.2.1 Description

The membrane seal was used on the S-II in conjunction with the helium-purged, foam-filled honeycomb insulation system described in Paragraph 6.1.1.1.

An inaccessible tangential junction area is formed at the forward skirt-forward bulkhead interface of the S-II (V7-530049). This area would be difficult to insulate and impossible to leak check and repair without removing the forward skirt. Consequently, the region is left uninsulated and isolated by use of the membrane seal. During cryogenic operations, a helium purge prevents cryopumping and provides a means of diluting, as well as detecting, any hydrogen leakage. In addition, the membrane prevents the intrusion of water into the cavity.

This concept consists of laminating a nylon fabric and gas-barrier plastic film to form a membrane. This membrane is then installed between the forward skirt structure and the insulation on the forward bulkhead (Figure 6.4.2.1-1).

It should be noted that a somewhat different system was used in conjunction with the spray-on foam insulation (Paragraph 6.1.4.1). A polyurethane-coated nylon fabric (debris barrier) of a similar configuration was installed in this same location. This system provided a sealed barrier to liquid water and a helium purge during cryogenic operations. No provision for detection of hydrogen leakage was included in this system. Details of this design are shown on NR drawing V7-531122.

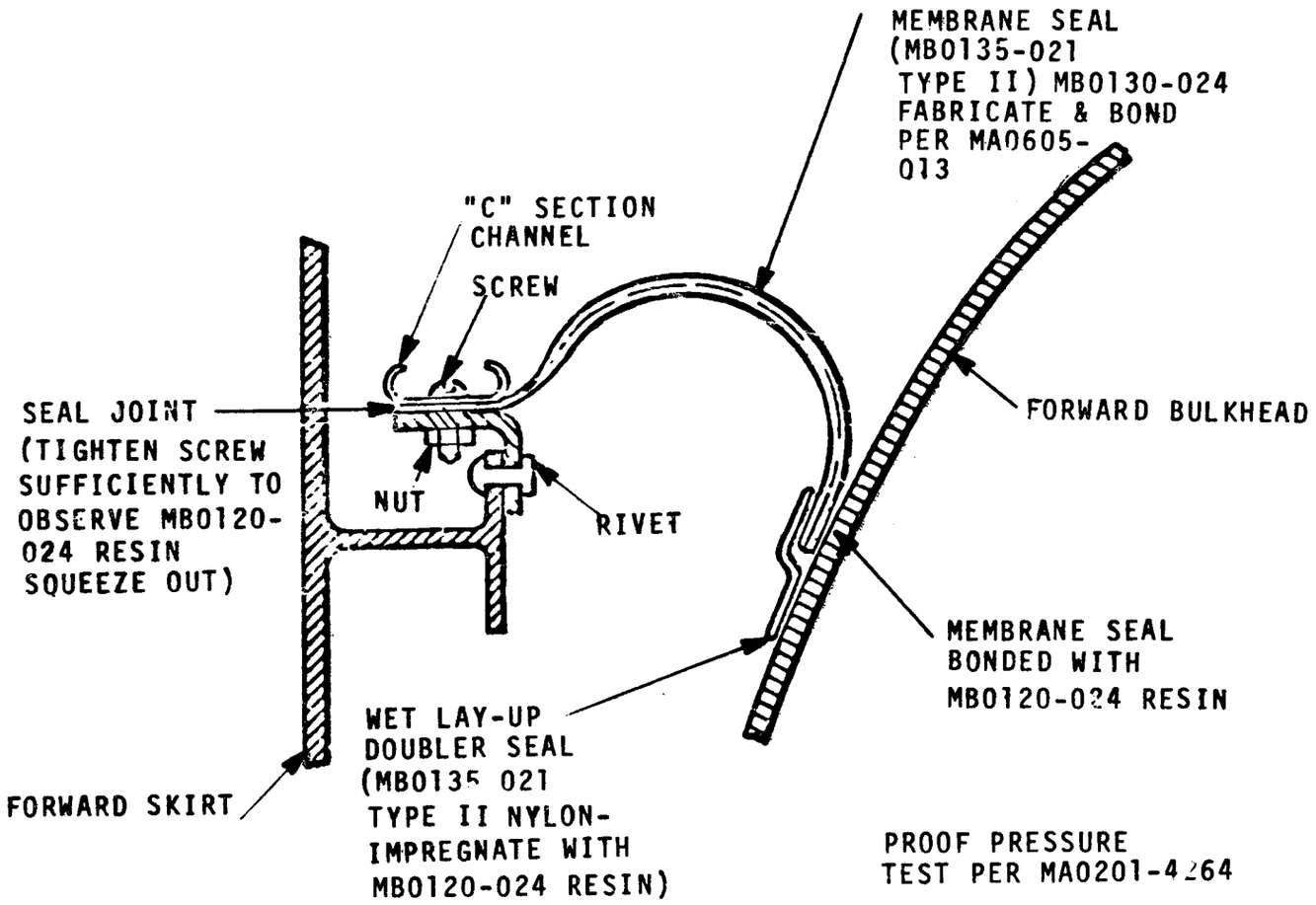


Figure 6.4.2.1-1. Typical Installation Profile of S-II Seal

Space Division
North American Rockwell

6.4.2.2 Application

a. Utilization: Tanks for cryogenic vehicles generally include complex structural joints or interfaces that are difficult to insulate (Paragraph 5.3.4.2). A joint of this type exists on the S-II stage in the area where the forward skirt is slipped down over the juncture between the forward bulkhead and upper sidewall cylinder. A membrane was installed to retain helium-purge gas within the juncture volume at slight positive pressure, thus providing thermal protection as well as preventing accidental intrusion of mechanical debris or water into the sensitive juncture area.

Systems of this type can be utilized in any similar structural design for ground installation as well as flight vehicles.

b. Performance Characteristics: Thermal performance of this system was not measured on the S-II stage since it is a part of the total stage system. Performance as a purge barrier was acceptable. Repairs were required, however, because its location at a low point in the forward skirt made it susceptible to mechanical damage.

Performance as a barrier to large quantities of rain was enhanced by application of a polyurethane solution.

c. System Limitations: The system is principally limited by the flexural capability of the seal material at the cryogenic temperature. On the S-II this was demonstrated by inflating and deflating the seal with nitrogen gas at -130 F (Reference 47).

d. Design Problems: Design problems and solutions are listed in Table 6.4.2.2-1.

Table 6.4.2.2-1. Membrane Seal Design Problems and Solutions

Problem	Solutions
System difficult to bond due to location	1. Adapt design to permit bonding of major joints prior to installation of forward skirt; limit post installation bonds to closeouts 2. Adapt design to utilize bolted sections where possible
Failure in fabric due to flexure	Orient fabric sections to proper direction for structural integrity
Water permeates through seal	Coat seal with polyurethane adhesive solution

e. Design Verification Tests: Laboratory tests (Reference 47) demonstrated effectiveness of the seal material and coating against permeation of nitrogen gas and against water seepage under two inches of hydrostatic head. It also demonstrated acceptability to withstand structural flexing at -130 F.

6.4.2.3 Thermal Performance

The thermal performance of the membrane seal by itself has little meaning. The area below the seal is closed off and may be filled with air, nitrogen, or helium.

In any joint, especially one with the junction turned up, there is a major concern regarding collection of foreign material, water, and cryopumped gas. These affect the mechanical strength and heat transfer of the area. The heat transfer requirements are such that the area must be filled with helium. The results of the analysis are provided in Paragraph 7.3.4.2 and are not repeated here.

The heat transfer rate with the cryopumping of air into the J-joint area without the membrane seal will be about 47,500 Btu/hr on the ground and about 6,000 Btu to the LH_2 during S-II operation. When the membrane seal is installed and the area filled with helium, cryopumping is prevented, the LOX sensitivity problem is eliminated, and the heat rate is reduced to 35,500 Btu/hr and 5,000 Btu during S-II operation.

6.4.2.4 Structural Performance

The significant factor affecting the structural integrity of the membrane seal is the critical loading that occurs as a result of differential pressure across the seal and the differences between diametrical deflections of the forward skirt and LH_2 tank forward bulkhead. The bond between the membrane seal and forward bulkhead must be sufficient to withstand these peeling stresses.

6.4.2.5 Material and Processes

a. Material:

1. Adhesive: Polyurethane resin system (MB0120-024).

2. Film: Polyvinyl fluoride material (MB0130-024).

3. Fabric: Woven nylon cloth (MB0135-021).

b. Process: The installation and fabrication of the membrane seal is in accordance with MA0605-013.

1. Environment: The temperature of the bonding and laminating is maintained at 60 to 90 F with a relative humidity of 70 percent or less.

2. Tooling: Laminating molds and working area are coated with polytetrafluoroethylene (TFE) or equivalent.

3. Surface Preparation: All metal faying surfaces are abraded with Beartex pads followed by a solvent-wipe in accordance with MA0110-010. Organic faying surfaces are only solvent-wiped with MEK.

4. Application of Adhesive: All application of the polyurethane adhesive must be completed within two hours after addition of the curing agent. Pressure must be applied within three hours after mixing.

5. Fabrication of Detail Segments:

   (a) Gas Barrier Film: The gas barrier film is thermo-vacuum formed wrinkle-free and without splice joints at a temperature not exceeding 400 F.

   (b) Nylon Laminate: The gas barrier film is located and retained on the laminating tool. The faying surfaces are then wiped with MEK in accordance with MA0110-010. After the faying surface is cleaned, apply a uniform brush coat of polyurethane adhesive and one ply nylon fabric are applied. An additional coat of polyurethane adhesive is applied to the nylon laminate. A minimum vacuum of 22 inches of mercury is applied and excess adhesive is removed from the assembly. The assembly is cured at ambient temperature (70 to 120 F) for 12 hours, then 4 hours at 160 ± 10 F or 7 days at ambient temperature (70 F minimum) while maintaining a vacuum of 22 inches of mercury. The vacuum may be removed after 24 hours. No stress is to be applied for seven days or until production test specimens meet the design requirements.

6. Bonding to LH_2 Bulkhead: The faying surface and the area on the LH_2 bulkhead is solvent-wiped with MEK. A brush coat of polyurethane adhesive is applied to all joints and overlap of segments and cured at ambient temperature with a contact pressure of 2-10 psi.

7. Installation to Forward Skirt: The membrane seal is first prefitted to the forward skirt. A uniform brush coat of polyurethane is applied to all faying surfaces and screws after being solvent-cleaned with MEK. The seal joint is assembled and screws installed and tightened until resin squeezes out. The polyurethane adhesive is cured at ambient temperature prior to pressurizing the membrane seal. Care must be taken at time of installation to prevent folding, creasing, or inadvertent binding of the membrane to itself or other surfaces.

6.4.2.6 Manufacturing

a. Description: The nylon resin impregnated seal (membrane seal) was installed as a debris barrier between the forward bulkhead and the forward skirt. Holes were drilled from the membrane seal retainer into the internal skirt structure, then bolted with mechanical fasteners. The retainer, a C-section channel, is basted with resin, then squeezed with screws to form a sealed joint.

At the forward bulkhead a wet layup doubler seal was prefit and vacuum pressure bonded over the membrane to assure a bonded seal. Upon completion, the membrane assembly was proof-pressure-tested to verify proper sealing of the bonded seal. Installation of the seal is shown in Figure 6.4.2.6-1.

b. Tooling and Equipment: Tooling and equipment was similar to that described in Paragraph 6.1.8.6.

6.4.2.7 Quality Assurance

a. Raw Material Validation: Perishable raw materials are tested periodically to verify continued conformance to specification requirements. See Table 15.3.1.4-1 for the level of testing performed on raw materials applicable to this design.

b. Subassembly Process Control (MA0605-013):

1. Visual Inspection: All production parts were visually inspected for indication of improper cure, fractures, or other visible defects as follows:

(a) There were no holes which penetrated through the laminate.

(b) There were no delaminations, unbonded areas, or air pockets.

(c) The entire laminate was fully cured and tack-free.

(d) Starved areas were not allowed (defined as areas in which the fabric was not uniformly impregnated with sufficient resin).

(e) Foreign objects or substances in the laminate that reduced the serviceability of the part were not allowed.

(f) Wrinkles 0.012 inch or less in height were permissible immediately adjacent to sharp changes in contour.

(g) Excessive resin buildup in areas of sharp change in contour could not exceed 0.015 inch in thickness.

2. Process Verification Coupons: Metal-to-metal lap shear strength test coupons were fabricated simultaneously with the joining of the detail segments and simultaneously with the bonding of the segments to the forward LH_2 bulkhead. Test specimens were required to exhibit a minimum strength of 500 psi.

c. Quality Verification of Final Assembly (MA0201-4264):

1. Proof Pressure and Gross Leak Test: The membrane seal cavity was pressurized with clean air or nitrogen to 0.4 - 0.5 psig and held for 15 minutes. If leakage exceeded 150 scc/second (0.32 scfm), the pressure was dropped to a minimum of 0.3 psig. If the leakage still

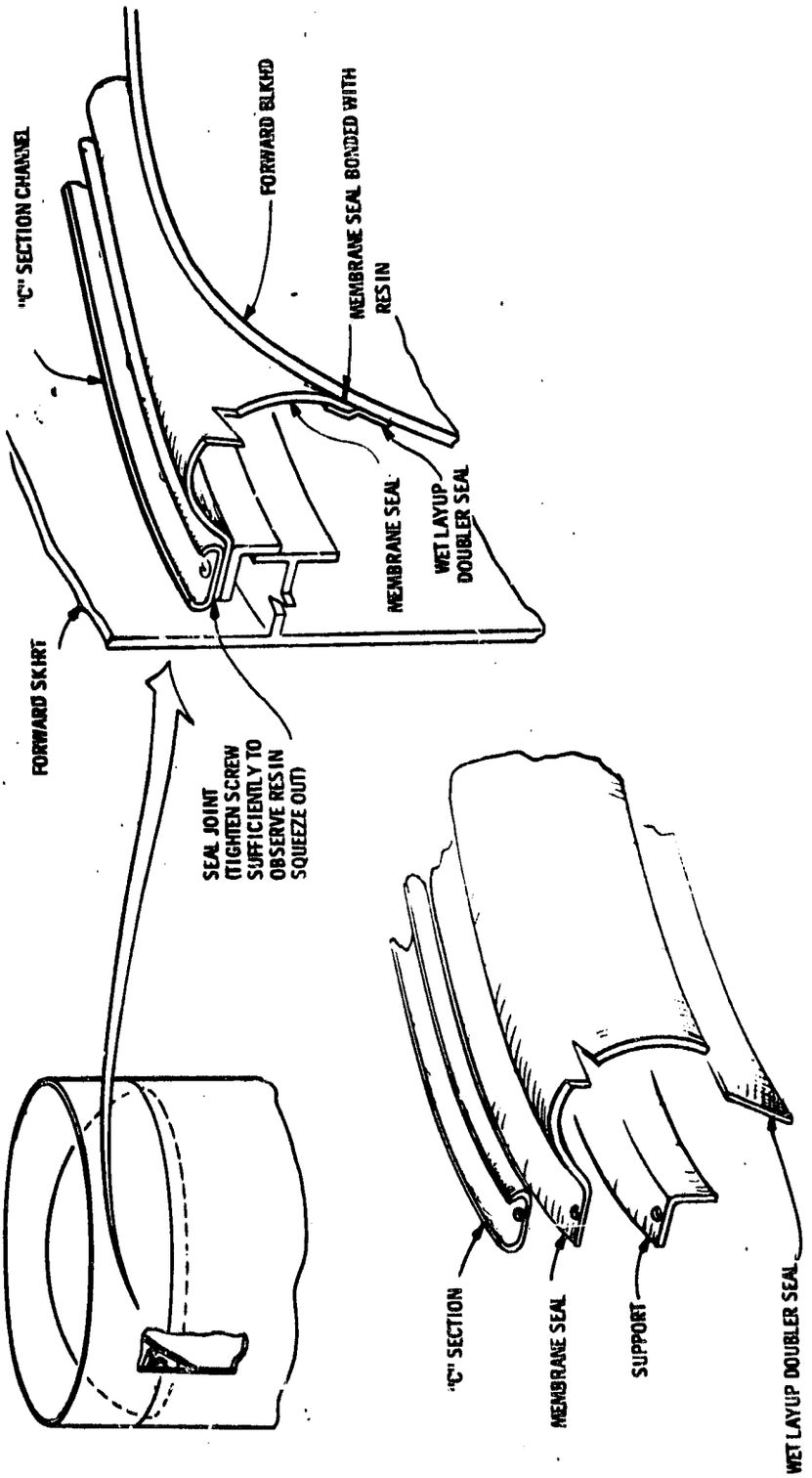


Figure 6.4.2.6-1. Membrane Seal

exceeded 150 scc/second, the leaks were located by the bubble fluid technique noted in MA0615-003. The system was repaired and retested until the noted leakage requirements were met as a condition of final acceptance.

6.4.2.8 Repair and Maintenance

No standard repair or maintenance procedures were developed.

6.4.2.9 Reliability

The failure mode analysis is presented in Table 6.4.2.9-1.

Table 6.4.2.9-1. FMEA—Membrane Seal

Component	Failure Mode	Mission Effect
Membrane Seal	Rupture	Liquid nitrogen forms in the forward bulkhead uninsulated area, the heat transfer rate increases, LH_2 boiloff rate increases, inability to detect hydrogen leakage in the area.

6.4.2.10 Safety

a. Fabrication and Installation: Particular attention should be given to cleaning the area below the membrane prior to its installation. Because of the location between the forward skirt and the forward bulkhead, a trap is made for loose equipment, chips, and debris that must be removed.

Care should be used during the installation of component parts of this system to insure that no damage is done to components that have been previously installed.

Additional safety requirements are given in Paragraph 6.1.1.10.

b. Membrane Seal Use: The functional testing of the membrane seal will include a proof-pressure test of 125 percent of the maximum operating pressure. The applied membrane is fragile and damage is easily incurred after the installation is complete. The membrane must be protected when any work is in progress in the forward skirt area.

The helium purge gas should be verified to be free of contamination prior to use. When used to insulate hydrogen tanks 2 percent oxygen in the purge gas could combine with leaking hydrogen to form an explosive mixture. Contamination of any gas with the helium would condense on tank surfaces and solidify and block purge passages or provide a pressurizing source that could separate the membrane from the tank when the solidified gases warmed up and vaporized.

The purge gas should be introduced into the cavities in quantities sufficient to insure that negative pressure does not develop in the honeycomb. When the sidewall is exposed to cryogenic temperatures the purge gas will contract. A positive pressure is necessary to insure that minute cracks or openings that are otherwise acceptable will not allow condensable gases to be forced into the purge channels by atmospheric pressure.

After each cryogenic exposure the membrane seal should be inspected for damage. Any damage should be repaired and tested prior to another cryogenic exposure.

Positive protection must be given the forward skirt area to prevent water from rain, condensation, or leakage draining down to the membrane seal. Means must be provided to minimize any water from getting in the area and for drying up the water that does get in.

6.4.2.11 Design Effectiveness

a. Cost: The manufacturing direct labor hours per square foot are considered to be an indication of the installation complexity of the insulation system and are derived from internal Manufacturing department records. These hours consist of fabrication, installation, and assembly effort and are an indicator of its relative cost. No data are available on costs for this system.

b. Schedule: The schedule flow times for this insulation system are as follows:

Procurement - 8 weeks.

Subassembly - 5 weeks.

Installation - 1 week.

Checkout - 1 week.

c. Weight: The total as-installed weight is 0.046 lb/ft^2 broken down as follows:

1. Film (MB0130-024) - 0.0172 lb/ft^2
2. Nylon (MB0135-021 Type II) - 0.0291 lb/ft^2

d. Thermal Performance: The Q of this system is 2000 $Btu/hr/ft^2$. The conduction coefficient of this system is 4 $Btu/hr\text{-}ft^2\text{-}^oF$.